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FUEL MEASURING PUMP PRESSURES AND THEIR EFFECTS ON PERFORMANCE.

BY LIEUTENANT JOHN CANOOSE, U. S. NAVY, MEMBER.

In considering the relative merits of various fuel measuring pump designs it appeared essential to know the pressure characteristics of each. Indicator cards taken of the pump cylinder pressures indicated that a study of the pressures obtaining in the suction receivers and suction lines of the pumps might be of value.

This study of receiver and suction line pressures was expected to show the relative merits of the float chamber, the suction standpipe, and the suction system utilizing no surge control means whatever. All three of these systems are in use in the service. Plates I, II and III show the three types of pumps considered.

Author's note: Credit is due Machinists Mate Harry P. Warren, U. S. Navy, for making most of the sketches for this article and for other valuable assistance.

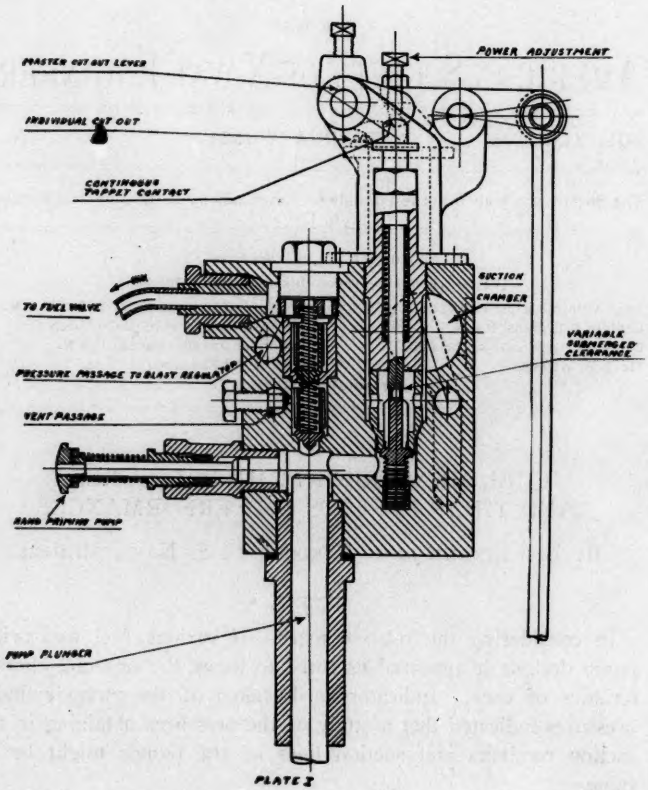

MASTER CUT OUT LEVER
INDIVIDUAL CUT OUT
CONTINUOUS TAPPET CONTACT
POWER ADJUSTMENT
SUCTION CHAMBER
VARIABLE SUBMERGED CLEARANCE
TO FUEL VALVE
PRESSURE PASSAGE TO GLASS REGULATOR
VENT PASSAGE
HAND PRIMING PUMP
PUMP PLUNGER

PLATE I

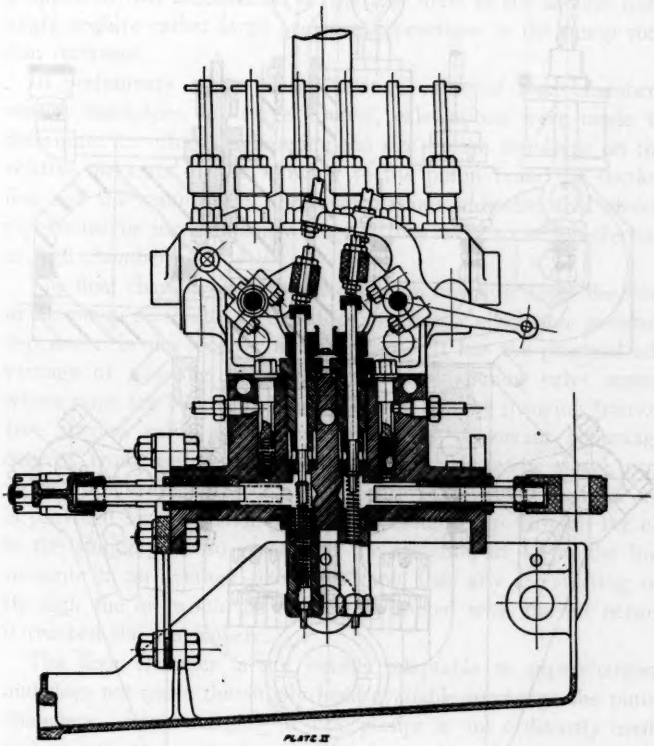
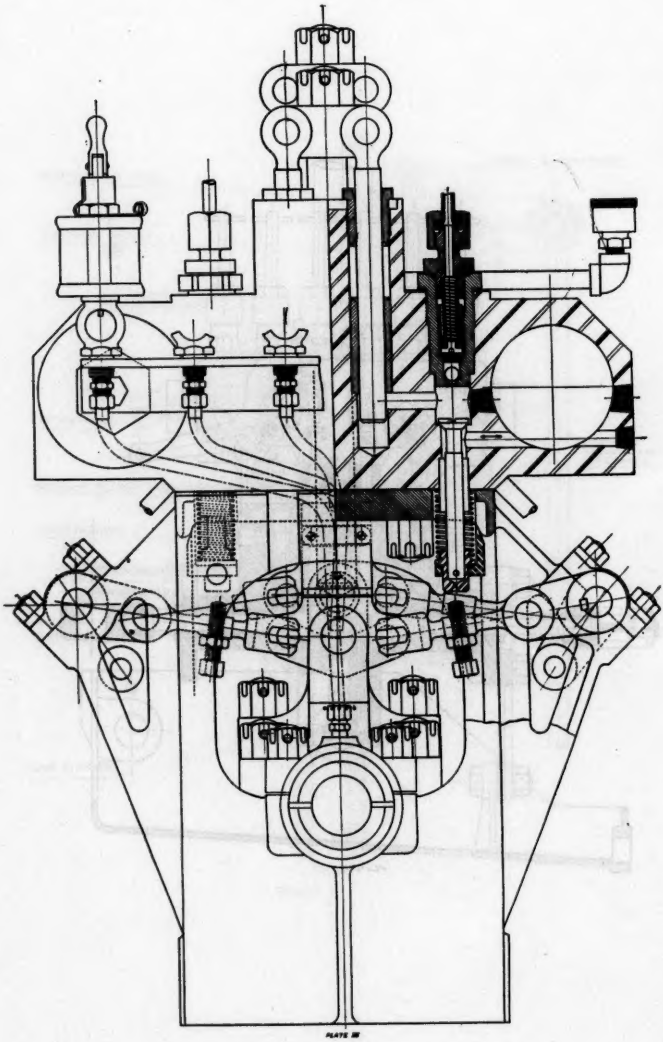


PLATE II



Suction flow in fuel measuring pumps is never steady. In most cases it is pulsating, but in some cases it is alternating. The frequency of the flow cycleage is comparatively very high, ranging from 200 to 450 cycles per minute. In view of these facts it appeared that acceleration of the fuel mass in the suction lines might require rather large pressure depressions in the pump suction receivers.

In preliminary study of the relative value of float chambers versus standpipes for surge control, calculations were made to determine the effect of changing the size of the standpipe on the relative amounts of fuel flowing to the pump from the suction line and the standpipe. These calculations indicated that standpipes must be inconveniently large if they were to be as effective as float chambers.

The float chamber separates the suction line flow from the flow in the pump receiver. It therefore practically eliminates pressure depression in the receiver due to surge. It has the practical advantage of allowing the use of unpacked suction valve stems, where same are of inverted vertical type, thereby insuring friction free suction valve action. Another very important advantage derived from use of the float chamber is the ready escape provided for entrained gas or air. A path for escape of gas or air is provided by the standpipe; but the distance up through the oil in the standpipe is so great, and the agitation of oil in the line so acute in an average sized standpipe, that any air starting up through the oil would be thoroughly mixed with the oil before it reached the atmosphere.

The float chamber is not readily adaptable to supercharging and does not make the supply head available to charge the pump chambers. Supercharging of fuel pumps is not ordinarily used; and at high pump speeds pressure depressions due to surging in standpipe systems more than compensate for the supply heads usually provided. It appears, therefore, that the only sound objection to the use of the float chamber for fuel pumps is the added complication involved.

In making the standpipe calculations, referred to above, the fuel system shown diagrammatically in Figure 1 was used as a basis. In this arrangement the maximum suction head is approximately five feet. There is 12.2 feet of two inch standard pipe

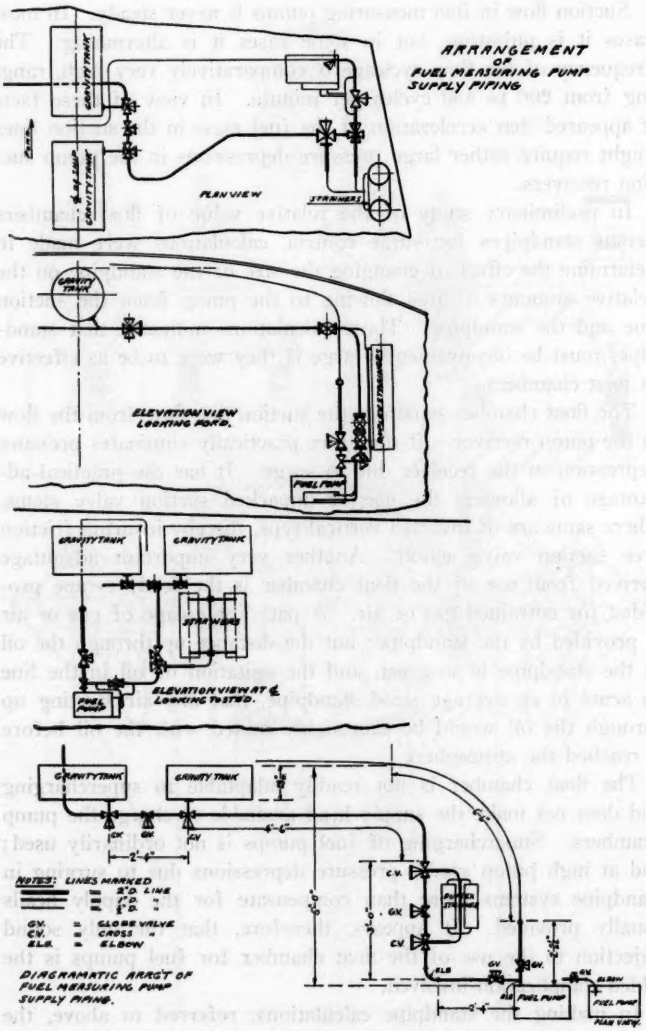

ARRANGEMENT OF FUEL MEASURING PUMP SUPPLY PIPING
PLAN VIEW
GRAVITY TANK
STRAINERS
ELEVATION VIEW LOOKING FORD.
FUEL TANK
ELEVATION VIEW AT ℄ LOOKING TO STBD.
FUEL PUMP
NOTES: LINES MARKED
2" O.D. LINE
1½" O.D. "
1" O.D. "
GV. = GLOBE VALVE
CV. = CROSS "
ELB. = ELBOW
DIAGRAMATIC ARRGT OF FUEL MEASURING PUMP SUPPLY PIPING.

FIG. 1

in the suction line, exclusive of the strainer shunt, between the fuel pump and the forward tank. The standpipe is 2.2 feet high and is made of two inch standard pipe. When the fuel tank is full there is 2.8 feet of head above the top of the standpipe. To take care of this, a length of one half inch standard pipe is run up in a sloping manner to a point above the tank. Of this length 6.5 feet is below the fuel level with the tank full and with fuel in suction line at rest. With the pump in operation the level of oil in the standpipe line is somewhat lowered. It will be shown below that the standpipe to be most effective should be extended to maximum fuel height without reduction in diameter.

In making calculations on standpipe sizes, it is desirable to know the rates of fuel acceleration in the suction line. For some types of fuel pumps this acceleration would be proportional to the acceleration of the fuel pump plungers. The plungers are usually crank driven; so that they move in approximate simple harmonic motion. If, therefore, the suction valves were opened at the beginning of the suction stroke, the acceleration of fuel in the suction line would be simple harmonic provided no cavitation occurred. But in the pumps represented in Figure 1, the suction valves are not opened until mid-stroke, when engine is operating at full power. A perfect vacuum, therefore, exists in the pump cylinder when the suction valve is opened. Hence, there is an atmosphere of pressure acting across the oil in the suction line and standpipe to accelerate the oil; and to this must be added the head of the oil itself.

The following calculation shows what is to be expected from standpipes of uniform cross-section extending to maximum oil tank level and open to atmosphere at the top. Due to greater length, there is greater frictional resistance to flow in a suction line than in a standpipe of equal cross-sectional area; but since the frictional forces are small as compared with necessary forces required to overcome inertia of the oil, friction effects will be neglected.

Calculations are based on the formulae:

$$F = ma \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$S = 1/2\ at^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In these equations F is proportional to the cross sectional area of the pipe, and m is proportional to the length, L, of the oil column in standpipe or in suction line.

From (1), $a = F/m = (1/m)F$. And since F is constant for both standpipe and suction line and m is proportional to L,

$$a \propto (1/L) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In (2), t represents time of flow, and since the time of flow from the suction line is equal to that for flow from the standpipe, it can be considered as a constant. From this we get the relation

$$S \propto a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and, from (3) and (4),

$$S \propto (1/L) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The distance the fuel column moves in the suction line and standpipe is represented by S; and the ratio of the distances of flow from suction line and standpipe is represented by the ratio of the S's which is directly determined from (5).

Using the relation of (5) for the case of Figure 1, we get for the standpipe

$S_p = K/5$, and for the suction line

$S_L = K/12.2$, from which

$$\frac{S_p}{S_L} = \frac{K/5}{K/12.2} = \frac{12.2}{5} = 2.44$$

With this arrangement the standpipe would supply $100 \times 2.44/(2.44 + 1) = 71$ per cent of the charge. This case assumes that the standpipe is of the same area as the suction pipe, and that it extends vertically to the level of the top of the supply tank.

Were a two-inch standpipe run to the top of the tank in the same sloping manner as that shown of the half inch line of Figure 1, the ratio of lengths would be 8.7 to 12.2 = 1 to 1.4 in which case the standpipe would supply $1.4/2.4 \times 100 = 58$ per cent of the charge.

AREA RATIOS.

Changing the relative areas of the standpipe and the suction line will not affect the distance the oil columns move in a given

time, but will affect the relative quantities of oil moved. Considering the installation of Figure 1, the ratio of the area of the suction line to the area of the half inch standpipe extension line is 3.335 to .304, or 11.05 to 1.

SUPPLY RATIOS.

The ratio of supply is the product of the distance of flow ratio and the area ratios. Hence, for the case of Figure 1, the supply ratio is 1 to $(11.05/1 \times 1/1.4) = 1$ to 7.9 for standpipe in terms of suction line supply. Therefore, the standpipe would supply $(100 \times 1/8.9) = 12.65$ per cent of the total charge. This assumes that the one half inch line runs all the way down to the pump. It runs only two thirds of the way; so the amount of fuel supplied by the standpipe would be somewhat higher than 12.65 per cent.

The above computations indicate the effects of changing the size of a standpipe in relation to the suction line size. From these calculations and an inspection of Figure 1 it can be seen that the supply ratio changes with change in fuel level in the supply tank.

To test the theory outlined above, and to obtain experimental data of other nature, experiments were conducted on three types of fuel measuring pumps. One of these pumps was fitted with a float chamber, one with a standpipe similar to the arrangement of Figure 1, and the other had only one quarter inch vent line attached to the pump receiver, there being no standpipe nor float chamber provided. All three of these arrangements were standard for the pumps in question. No change was made, except that the pump system having the standpipe was fitted with glass standpipe of the same size as the original standpipe in order to observe the action of the oil in the standpipe.

NELSECO PUMPS.

Figure 2 (a) shows the suction line arrangement on the S-1 which is fitted with Nelseco engines. Figure 2 (b) shows the way the indicator was first attached to the suction line. This arrangement gave very accurate records of pressure fluctuations in the line. The connection as shown at Figure 2 (c) gave indicator cards showing the pressure fluctuations in the pump re-

ceiver chamber. In Figure 2 (c) two indicators are shown, but the one at "B" is the only one connected to the suction receiver. The one at "A" is connected to the pressure chamber by special fitting as shown in Figure 3. Figure 4 shows the general arrangement.

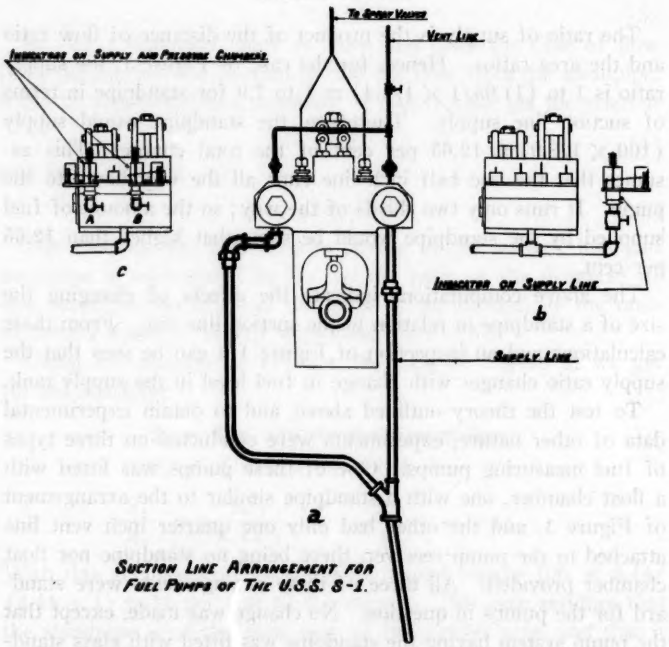


FIG. 2

Figure 5 (a) shows a card obtained with the indicator connected as shown in Figure 2 (b), while Figure 5 (b) shows a card obtained under identical running conditions with the indicator connected as shown in Figure 2 (c). Figure 5 (a) shows markedly the effects of fluid inertia, while in Figure 5 (b) the card lines are much more smooth, indicating the true pressure within the receiver. The arrangement of Figure 2 (c) was used in all subsequent tests.

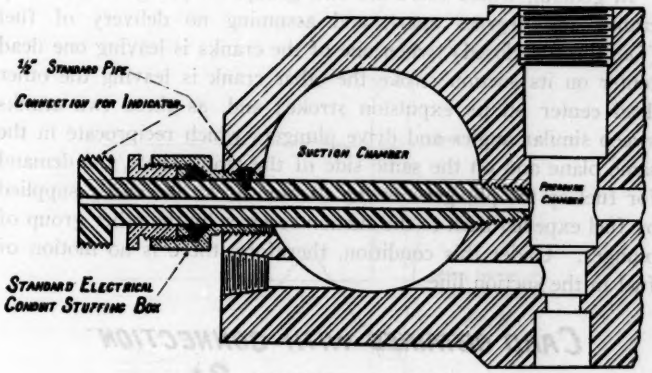
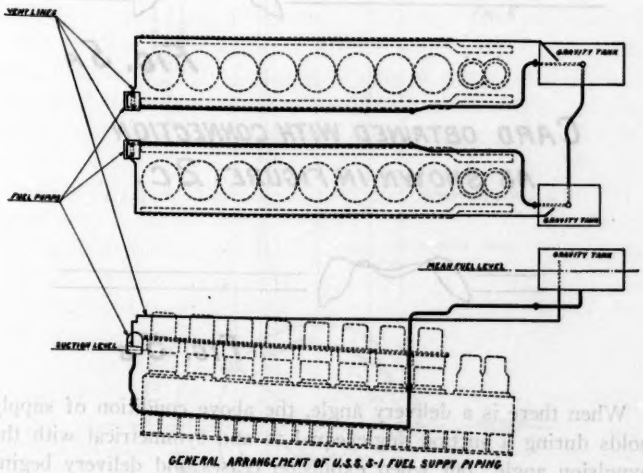


FIG. 3



GENERAL ARRANGEMENT OF U.S.S. S-1 FUEL SUPPLY PIPING

FIG. 4

In general, where there are two groups of plungers driven by cranks 180 degrees apart, and assuming no delivery of fuel (*i.e.*, throttle closed), when one of the cranks is leaving one dead center on its suction stroke the other crank is leaving the other dead center on its expulsion stroke; and, as these two cranks sweep similar angles and drive plungers which reciprocate in the same plane and on the same side of the crank shaft, the demand for fuel by the plungers on the suction stroke is exactly supplied by fuel expelled back to the suction receiver by the other group of plunger. Under this condition, therefore, there is no motion of fuel in the suction line.

CARD OBTAINED WITH CONNECTION AS SHOWN IN FIGURE 2b

FIG. 5A

CARD OBTAINED WITH CONNECTION AS SHOWN IN FIGURE 2c.

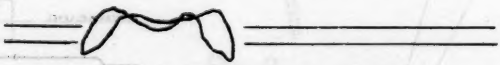


FIG. 5B

When there is a delivery angle, the above condition of supply holds during a suction angle equal to and symmetrical with the expulsion angle; but when expulsion ceases and delivery begins a vacuum is formed in the pump receiver by the plunger group on suction stroke which draws fuel from the suction line into the receiver. When the throttle is changed to increase the delivery angle the vacuum arc is increased correspondingly.

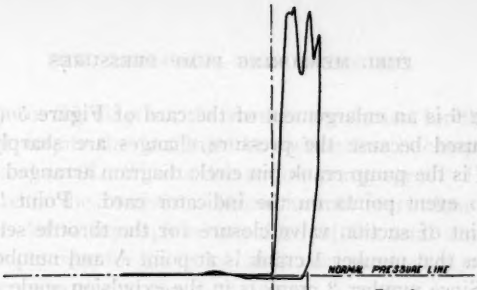


Fig. 9

Fig. 8

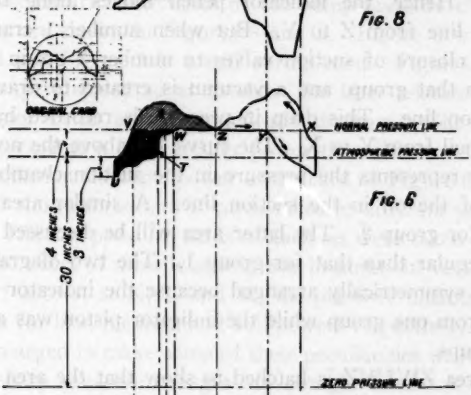


Fig. 6

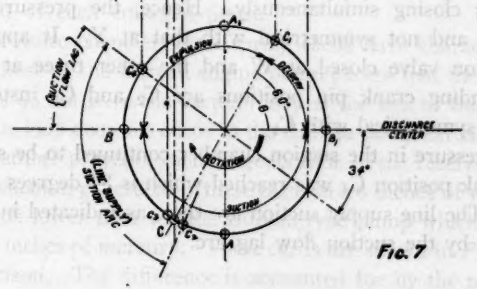


Fig. 7

Figure 6 is an enlargement of the card of Figure 5 (a). This card is used because the pressure changes are sharply defined. Figure 7 is the pump crank pin circle diagram arranged to project angles to event points on the indicator card. Point "c" is the mean point of suction valve closure for the throttle setting used.

Assume that number 1 crank is at point A and number 2 crank at A_1. Since number 2 crank is in the expulsion angle, number 1 plunger group is receiving fuel from group 2. When number 1 crank reaches point C expulsion from group 2 ceases and supply for group 1 must come from the suction line. So long as group 1 receives fuel from group 2, the pressure in the receiver remains normal. Hence, the indicator pencil moves along the normal pressure line from Z to Y. But when number 1 crank reaches point C, closure of suction valves to number 2 group stops supply from that group, and a vacuum is created to draw oil from the suction line. This drop in pressure is recorded by the indicator pencil from Y to X. The curve XZ above the normal pressure line represents the pressure in the suction chambers due to inertia of the oil in the suction line. A similar area ZWUVZ obtains for group 2. The latter area will be discussed because it is less regular than that for group 1. The two diagrams on the card are symmetrically arranged because the indicator drum was driven from one group while the indicator piston was affected by both groups.

The area ZWUVZ is hatched to show that the area representing pressures below normal is about equal to that representing pressures above normal. Points W, T and V are projected to the crankpin diagram. In this case the suction valves of the group were not closing simultaneously. Hence, the pressure drop is irregular and not symmetrical with that at Y. It appears that one suction valve closed at W and the other three at T. The corresponding crank pin positions are C_2 and C_3 instead of C which is symmetrical with C_1.

The pressure in the suction chamber continued to be subnormal until crank position C_4 was reached which is 34 degrees past dead center. The line supply suction arc then, as indicated in figure, is increased by the suction flow lag arc.

As shown in the diagram, the vacuum generation for this pump is very low despite the fact that the suction line is comparatively very long and small. This is due to low pump speed. However, the pressure in the receiver is below normal more than half the time, and is below atmosphere one-third of the total time. This provides ample time for air leaks but is very good when compared with the performance of the S-50 pumps.

At the time the suction line cards were taken an indicator was set up as shown in Figure 3 to take pressure-chamber cards. Receiver cards were taken simultaneously at 105 B.H.P. and 890 B.H.P. Low pressure cards were also taken near these powers to determine vacuum characteristics of the pump pressure chambers. These cards are shown in Figures 8 and 9. Figure 8 is a weak spring card and Figure 9 is a stiff spring card. Figures 6, 7, 8, and 9 are superimposed so as to show the inter-relations of the three indicator cards and the crank-pin diagram. The card in Figure 8 represents a little greater power than that for Figure 9 which was taken at the same power as the card of Figure 6.

Figure 10 shows three sets of cards taken at different powers as indicated. The low pressure cards of each set were taken simultaneously. The effect of throttle setting was brought out very clearly.

Figure 11 shows, at K, L and M, the pressure chamber weak spring cards for low, medium and full powers respectively. These cards are enlarged to make some of their peculiarities more apparent. The sharp pressure changes are straight lines. As shown, there seems to be no relation between the angles these lines make with the vertical and the power at which the engine operated. The original cards bearing the cross-lines used for enlarging are shown to the right of each enlarged figure.

These pressure chamber weak spring cards have characteristics similar to those of the Bureau engine pump except that the Bureau pump cards do not have the vacuum loop at the end of the suction stroke. The loop does not occur in the Bureau pump cards because the float chamber prevents vacuum generation in the receiver. The maximum vacuum generated in these cards in 8.6 inches of mercury. This is much lower than for the Bureau type pump which usually exceeds 20 inches of mercury. These cards are shown in Figure 12 for comparison. The difference is accounted for by the relatively

large suction valve of the Nelseco pump and its lower speed. The degree of vacuum generation is less than one-half that of the Bureau 1000 H.P. type; but due to suction flow lag in the Nelseco pump, the vacuum exists for a longer period of time in this pump than in the Bureau type. This prolongs the time for air leaks past the suction valve stems and the plungers.

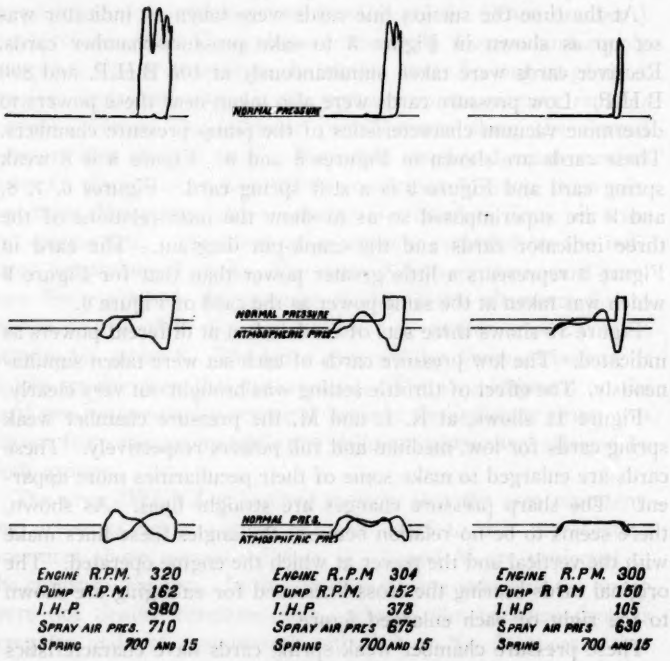
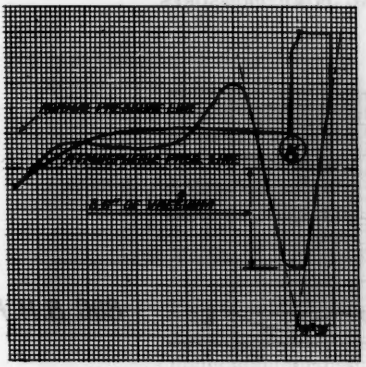


FIG. 10

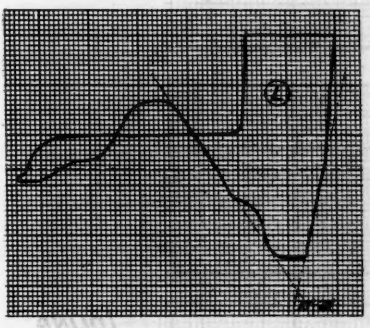
Figure 13 shows enlarged stiff spring cards corresponding to the weak spring cards of Figure 11. The lines have considerable slope from the vertical which would obtain with a perfectly rigid system pumping a non-compressible fluid. Part of this slope angle is accounted for by displacement of the indicator piston with rise of pressure. The exact amount of this displacement was deter-



_____, 19

_____, SPRING SCALE 1"

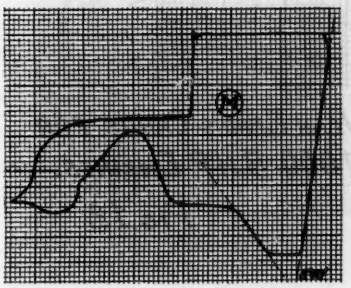
105 B.H.P. 300 R.P.M.



_____. 19 ENGINE NO

_____ SPRING SCALE, 1"= 15

378 B.H.P. 304 R.P.M.



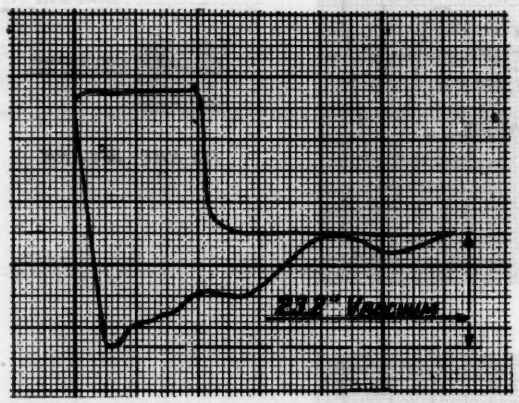
_____, 19 ENG

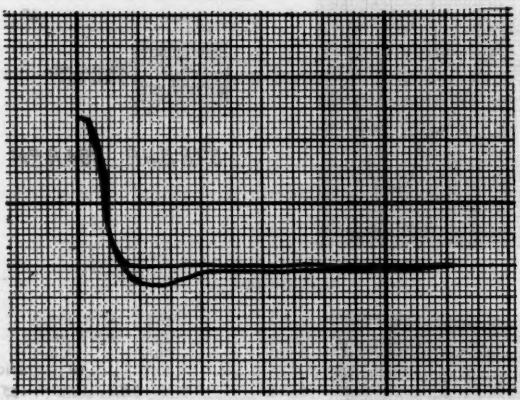
_____ SPRING SCALE, 1"= 15

890 B.H.P. 320 R.P.M.

PRESSURE CHAMBER WEAK SPRING CARDS

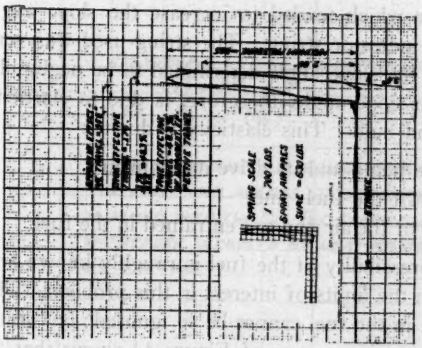
FIG. 11





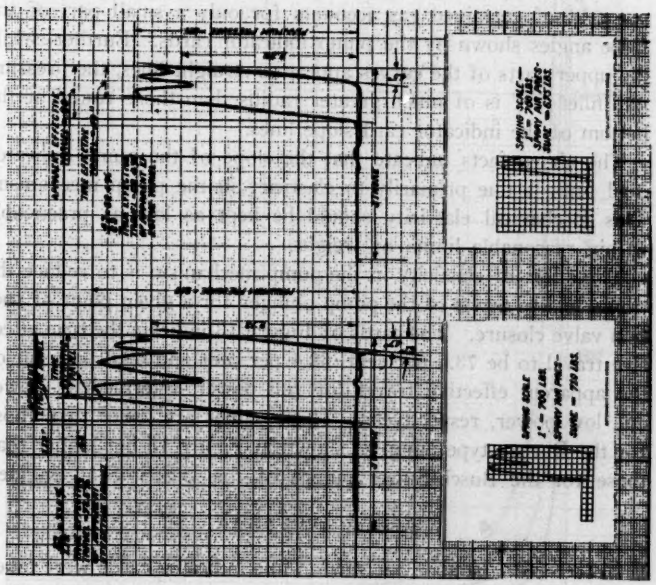
PRESSUE CHAMBER WEAK SPRING CARDS FOR BUREAU TYPE 1000 B.H.P. ENGINES.

FIG. 12



PRESSURE CHAMBER STIFF SPRING CARDS.

Fig 13



mined and found to account for only a very small part of the slope angle. Another factor which tended to increase the slope angle was the stretch of the indicator string. The string used was very short and its effect on the slope angle determined to be negligible. The major part of the slope angle, therefore, is due to elasticity of the pump system and fluid. This elasticity is due to:

(*a*) Elasticity of the pump and its drive mechanism;
(*b*) Compressibility of the fuel; and,
(*c*) Compressibility of the air and gas entrained in the fuel.

The degree of compressibility of the fuel is roughly known and can be neglected within the limits of interest in this problem. The effect of gas entrained in the fuel cannot be so ignored; but study of the polytropic compression curves of Figure 14 shows that 25 per cent of entrained gas accounts for only a small part of the slope angles shown by the pump indicator cards. Further, while the upper parts of the curves appear as straight lines, the pressure rise fillet "c" is of much greater radius than those found at the bottom of the indicator card slope lines.

The above facts indicate that the slope of the pump indicator card lines is due primarily to elasticity in the pump mechanism. This mechanical elasticity should be kept as low as practicable within reasonable limits of weight.

The effect of elasticity in the pump mechanism is to reduce the true effective travel of the pump plunger for a given point of suction valve closure. The cards of Figure 13 indicate the true effective travel to be 73.5 per cent, 62.4 per cent and 48.3 per cent of the apparent effective travel for full power, intermediate power and low power, respectively. These values are lower than those for the Bureau type pump as shown in Figure 15 but higher than those for the Busch-Sulzer pumps of the U.S.S. S-50 engines.

BUREAU TYPE PUMP.

No receiver chamber nor suction line indicator cards were taken on the Bureau type pump because that pump is fitted with a float chamber which reduces receiver pressure fluctuations to negligible value. The pressure chamber cards for the Bureau pump, shown in Figures 12 and 15, compare favorably with the two other types considered.

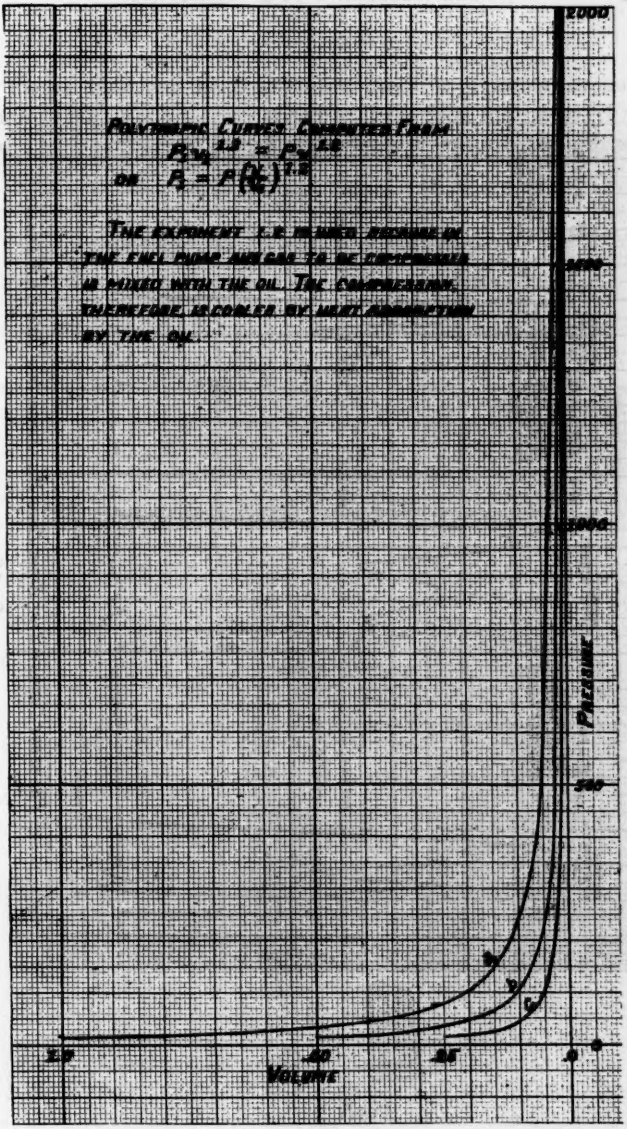

Polytropic Curves Computed From
$P_{1.2}^{1.2} = P_{2.2}^{1.2}$
or $P_1 = P_2 \left(\frac{V_2}{V_1}\right)^{1.2}$
The exponent 1.2 is used because the fuel pump and gas to be compressed is mixed with the oil. The compression therefore is cooler by heat absorption by the oil.
2000
1000
500
Pressure
Volume
40
20
0
a
b
c

Fig. 14

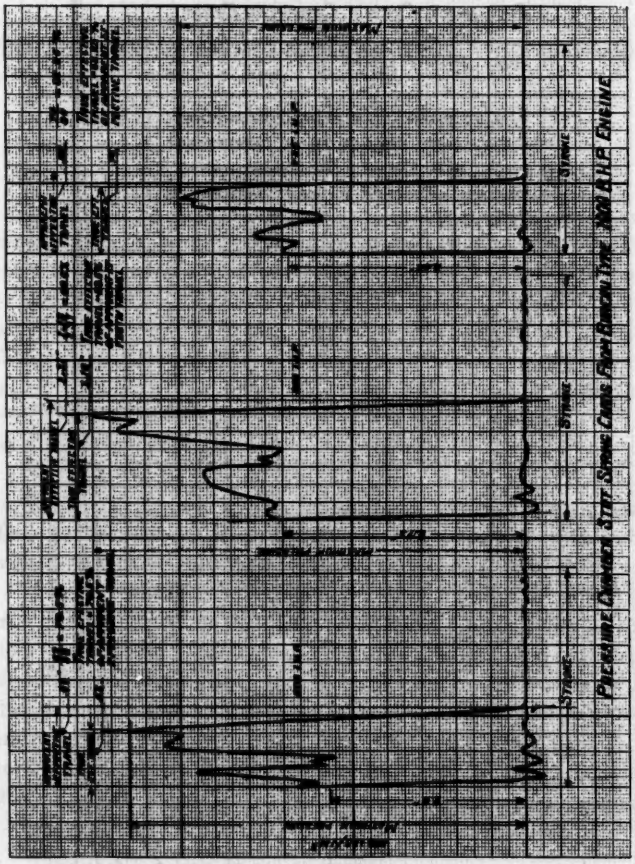


FIG. 15

BUSCH-SULZER PUMP.

Figure 16 shows the arrangement used for attaching the indicator to the suction receiver chamber of the S-50 fuel pump. Figure 17 shows connection used to attach the indicator to the pressure chamber.

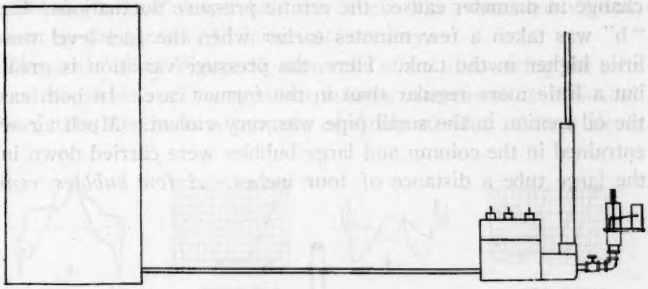


FIG. 16

FIG. 17

Figure 18 shows receiver cards taken at 300 R.P.M. and 650 H.P. with gravity tanks nearly full. The oil level is indicated. The standpipe was constructed of glass in order to study the column action. It will be noted that on card "a" the receiver pressures are very erratic. This is due to the oil level being near the change in pipe diameter. The reciprocation of the oil past this change in diameter caused the erratic pressure fluctuations. Card "b" was taken a few minutes earlier when the fuel level was a little higher in the tank. Here, the pressure variation is greater but a little more regular than in the former case. In both cases the oil motion in the small pipe was very violent. Much air was entrained in the column and large bubbles were carried down into the large tube a distance of four inches. *A few bubbles, rising*

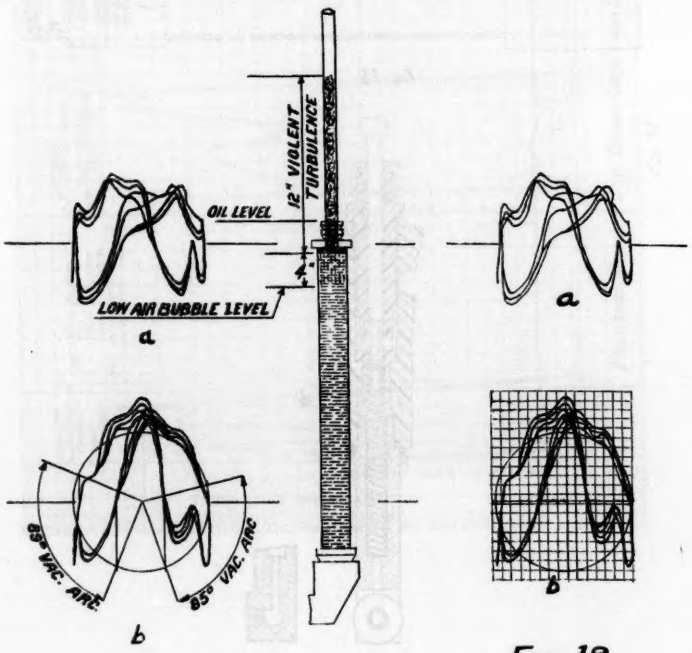


FIG. 18

regularly, were seen passing up the column from the bottom. This seemed to indicate air expulsion from the pump during the expulsion angle, which air must have reached the pump by passing the plungers or suction valve stems.

On card " b" is constructed the crank pin circle upon which are projected the limits of vacuum duration. This is seen to be a total of 174 degrees or almost half the time. The maximum vacuum shown by the cards is 15 inches of mercury.

The card " a" of Figure 19 shows the effect of lowering the level of oil as shown. The apparent column movement is indicated. Above this there was a mixture of finely divided oil and air in

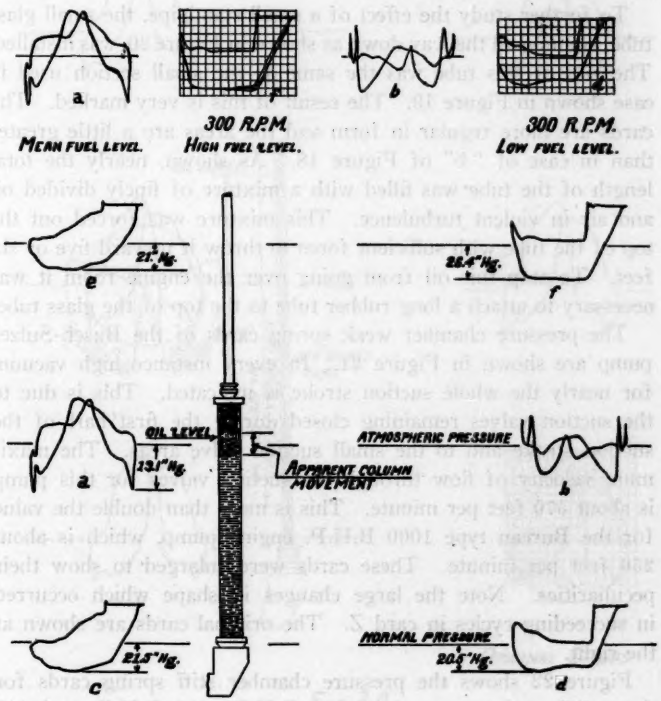


FIG. 19

violent motion. The vacuum loops are very much reduced due to the shorter column of oil to be accelerated. Card "b" of this figure shows the effect of further lowering the oil level.

Cards "c" and "d" show pressure chamber weak spring cards taken simultaneously with "a" and "b" respectively.

The cards at "e" and "f" were taken under conditions as shown, during the same test runs in which a, b, c and d were taken. They are shown here to emphasize the fact that the vacuum characteristics of the pump are very erratic, changing considerably over 10 or 15 minute intervals with no change whatever in the throttle setting. The original cards for diagrams a, b, d, and f are shown at the top of the figure.

To further study the effect of a small standpipe, the small glass tube, running all the way down as shown in Figure 20, was installed. The size of this tube was the same as the small section used in case shown in Figure 19. The result of this is very marked. The cards are more regular in form and the areas are a little greater than in case of "b" of Figure 18. As shown, nearly the total length of the tube was filled with a mixture of finely divided oil and air in violent turbulence. This mixture was forced out the top of the tube with sufficient force to throw it upward five or six feet. To stop this oil from going over the engine room it was necessary to attach a long rubber tube to the top of the glass tube.

The pressure chamber weak spring cards of the Busch-Sulzer pump are shown in Figure 21. In every instance high vacuum for nearly the whole suction stroke is indicated. This is due to the suction valves remaining closed during the first half of the suction stroke and to the small suction valve areas. The maximum velocity of flow through the suction valves for this pump is about 570 feet per minute. This is more than double the value for the Bureau type 1000 B.H.P. engine pump, which is about 250 feet per minute. These cards were enlarged to show their peculiarities. Note the large changes in shape which occurred in succeeding cycles in card Z. The original cards are shown at the right.

Figure 22 shows the pressure chamber stiff spring cards for three different powers, about 550 B.H.P., 475 B.H.P. and 440 B.H.P. The rise and fall of pressure lines are generally very

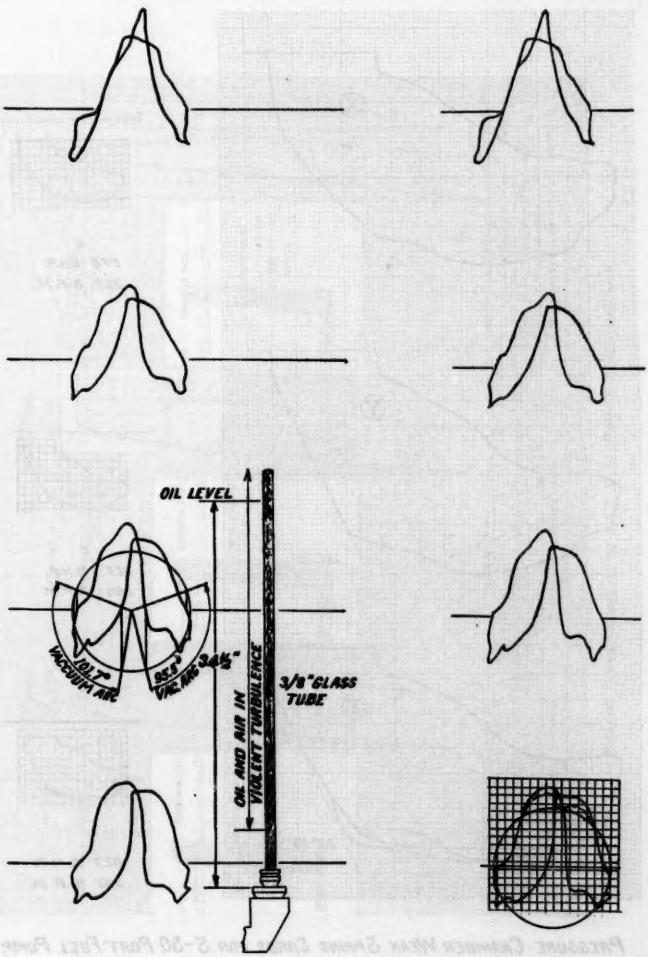
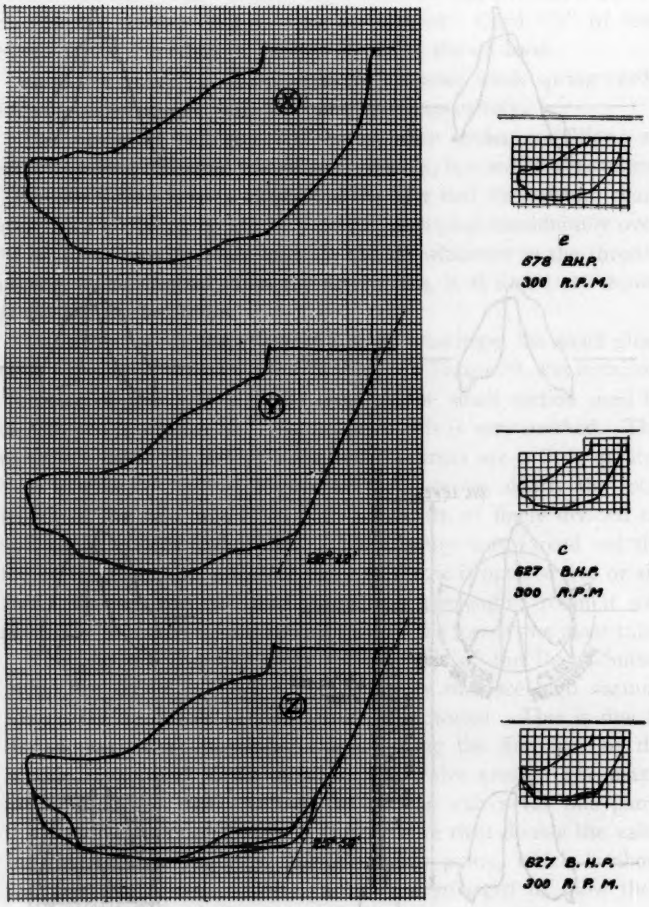
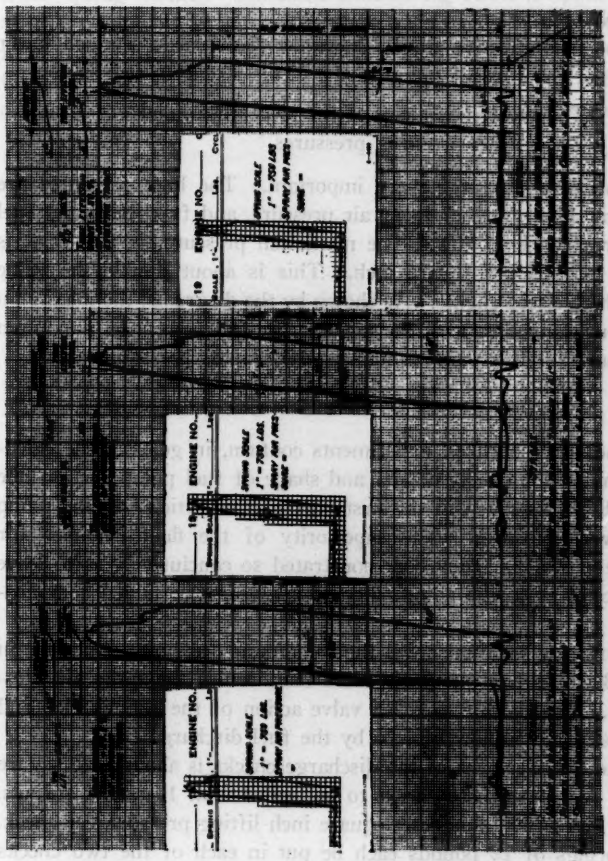

OIL LEVEL
101.7" VACUUM ARC
95.5" VAC. ARC
34½"
3/8" GLASS TUBE
OIL AND AIR IN VIOLENT TURBULENCE
ORIGINAL CARDS

FIG. 20



PRESSURE CHAMBER WEAK SPRING CARDS FOR S-50 PORT FUEL PUMP.
FUEL GRAVITY TANK ABOUT HALF FILLED.

FIG. 21



PRESSURE CURVES FROM THE U.S.S. S-50 PORT ENGINE FUEL PUMP

FIG. 22

irregular. This indicates unstable and irregular mechanical drive of the plungers, or faulty valve action, or both. The slope of these lines from the vertical includes greater angles than those for the Nelseco pump.

The true effective travel shown by these cards is much lower than for the Nelseco pump cards. This is due to two factors:

(*a*) The greater elasticity of the mechanism, and
(*b*) The greater working pressures.

The latter factor is very important. The high pressures are due to slightly higher spray air pressure, and fuel check and fuel line resistance to flow. The maximum pressure, in this case, is 1635 pounds per square inch. This is about double the value for the Nelseco engine. As shown by the diagrams, the maximum pressure increases with the power. At full power the maximum pressure for this pump is about 1700 pounds per square inch.

GENERAL.

The above outlined experiments confirm, in general, the calculations on the effects of size and shape of fuel pump suction line standpipe, as given in the first part of this article, on the pump receiver pressures. The superiority of the float chamber for surge control is believed demonstrated so conclusively as to leave no doubt as to the advisability of adopting this added complication.

Referring to Figure 22, the maximum pressures obtaining in the Busch-Sulzer pump are more than double the spray air pressures. This is due to relief valve action of the fuel checks, and to resistance to flow offered by the fuel discharge lines.

The effective area of the discharge checks is about 1/20 square inch. Suppose these checks to be loaded with 10 pound springs. This gives 200 pounds per square inch lifting pressure per check. If springs of 12 pounds each be put in each of the two checks the lifting load will be changed $4 \times 20 = 80$ pounds. This would extend the line X Y of Figure 22 about 1/15th of its length and reduce the true effective plunger travel by $1/15 \times 50 = 3.3$ per cent. This shows a probable effect of pump mechanism elasticity on the delivery balance between pump units. Variation in the

resistances of the various fuel lines leading to different working cylinders will produce the same effect as variation in the discharge check spring loading. This load unbalancing effect is common to all fuel pumps but proportional to elasticity of the mechanism. It is desirable, therefore, that the pumps be made as rigid as practicable; that fuel leads have the same flow resistance; and that discharge valve springs be given the same initial compression.

SOME NOTES ON PROPELLER OPERATION.

By Comdr. H. F. D. Davis, U.S.N., Member.

It often happens that when an accident occurs or repairs are made, resulting in changes in the machinery of his ship, the operating engineer looks about, sometimes in vain, for measures or previous experiences which may indicate to him what to expect under the changed conditions. The following cases involving propellers have been taken from actual reports and are believed therefore to be good criteria by which to judge similar cases. Some discussion elaborating on the reports and some conclusions are also added.

THE EFFECT OF UNBALANCE OF PROPELLERS.

Case I.—A battleship; 4 shafts; three bladed propellers.

During a full power run, at 0250 September 4, 192-, the ship then making about 164 R.P.M. (nearly 21 knots) a noticeable increase in vibration was felt throughout the ship. Investigation, made immediately, having showed the machinery to be operating satisfactorily, except for this increased vibration, it was decided to continue the run until further difficulty became evident. The remaining forty minutes of the full power run were completed without further increase in vibration and eight hours of the smoke prevention run (152 R.P.M.) followed. The data taken showed that at the time of the increase in vibration the power absorbed by two of the four shafts, in order to maintain the 164 revolutions, dropped off about 18 and 12 per cent respectively. After completion of the run it was found that a blade had been lost from propellers numbers one (broken 4 inches from the hub) and two (broken 8 inches from the hub). It was found thereafter that the ship could operate at a steady speed of 10 to 12 knots with negligible vibration, but that in accelerating or decelerating or backing there was considerable vibration.

In connection with this case it is of interest to note that the part of No. 1 propeller which broke off weighed approximately 1210 pounds and the center of gravity thereof was 43 inches from the axis; the part of No. 2 propeller which was lost weighed approximately 1344 pounds and the center of gravity thereof was 41 inches from the axis; the centrifugal forces due to the unbalance were therefore, at 164 R.P.M., for No. 1 propeller 35,860 pounds and for No. 2 propeller 34,200 pounds, for reduced speeds being in proportion to the squares of the revolutions. Noting that the strut bearings each had an area of approximately 960 square inches, allowing for grooves between the lignum vitae strips, the additional loads on the wood of the strut bearings due to the centrifugal forces as calculated above are 37 and 35 pounds per square inch respectively. It appears that in this case there were no other complicating factors and the bearings easily withstood these additional loads. The weight of a propeller being approximately 12,000 pounds, and of a propeller shaft 22,000 pounds it is evident that at 164 R.P.M. the centrifugal forces developed by the unbalance were sufficient to lift the propeller and the after part of the shafting during that part of each revolution when they acted upward. From the amount of vibration reported it is clear that there was not enough play in the strut bearings to allow undue pounding and accordingly there was no fear of trouble raised by the noise.

Case II.—A tanker; twin screw; three bladed propellers.

At about 1445 when steaming at 70 R.P.M., the ——— experienced "considerable vibration of the ship together with an increase of speed of the starboard engine." It was found that one blade had been lost from the propeller. The ship continued on her voyage making an average of 76 R.P.M. She steamed about 3000 miles thereafter before being docked, and at that time no other damage or bad results of the experience were reported.

Case III.—A tender; single shaft; 4 bladed propeller.

About 1401 April 25th when enroute Guantanamo to New York in a smooth sea making 56-58 R.P.M. the ——— lost a propeller blade, the break being close to the flange of the blade of the built up propeller. The ship continued the voyage making

45 to 50 R.P.M. for some time, then the log shows "changed speed to 50 revolutions and running smoothly." The ship entered drydock 30 April at which time no other trouble was reported as a result of the casualty and the following operation.

On 29 March the following year, this ship got underway at 0830 from St. Thomas for Guantanamo with a submarine in tow. At 1135 when making 51 R.P.M. it was reported that "a strong shock was felt, the engine appearing to slow up for a second, and then vibrating excessively for several minutes. The propeller shaft appeared slightly sprung. From 15 to 25 pounds per square inch less pressure noted on the gauges when making the same R.P.M. as before." Upon examination, one propeller blade was found broken off near the hub. Thereafter the ship made about 45 R.P.M. for 78 hours during the voyage to Guantanamo and ran for 104 hours at 40 to 45 R.P.M. enroute Guantanamo to the Canal Zone where she was docked 7 April. No damage except the broken blade was found upon examination.

Later in the same year the log shows "At 1:35 P. M. while running at full astern engine speeded up with considerable vibration. Upon examination the propeller was found to have thrown a blade." The ship thereafter steamed at 35 to 46 R.P.M. for 31 hours before docking, at which time no additional damage was found.

Case IV.—A mine sweeper; single shaft; four bladed propeller.

The ——— enroute from Pearl Harbour to San Diego, lost a propeller blade from her propeller, the meager report in the log stating "At 1210 reported to bridge that fuel oil tank in after shaft alley leaking due to working of shaft." "At 1605 underway 1/3 speed being towed by the ———." Thereafter for 130 hours the log shows that an average of about 95 R.P.M. was made good. Upon docking examination of the break showed that a large part of the section was an "old break."

DISCUSSION.

Cases II to IV inclusive are those in which the speeds of revolution are considerably lower than in Case I, therefore, the computations similar to those for Case I have not been carried out.

These cases have been cited particularly to confirm experiences when propeller blades have been lost and ships have operated thereafter without serious consequences of any kind. An investigation of recent cases of this kind failed to locate one in which there were reported any bad effects of operation with a propeller having a broken blade.

From the above cases and the discussion it may be safely concluded that a propeller may be operated when considerably out of balance without serious effects and that the seriousness of the vibration and pounding in the after bearing is a measure of the danger of further trouble.

THE EFFECT OF VARIATION OF PITCH ON VIBRATION.

Case I.—A destroyer; two shaft; three bladed propellers.

This ship with propellers which had been dynamically balanced prior to installation "ran a perfect full power trial and experienced no vibrations from the propeller in question."

The pitch measurements of the "propeller in question" were:

Blade No.	1	2	3
Pitch	116″.75	119″.2	118″.8

Average of three blades 118″.25

Variation in pitch maximum to minimum 2″.45

$$\frac{\text{Variation in pitch}}{\text{Average pitch}} = \frac{2.45}{118.25} = .0207$$

A safe conclusion to be drawn from this experience is that, when propellers are well balanced otherwise, considerable variation in pitch will not cause vibration. In this connection it may be noted that the Bureau of Engineering, particularly for other reasons, makes an effort to keep the variation of pitch of one blade from the mean of all at one per cent or below, that is less than one half that existing in the case cited above; also the Bureau requires that high speed propellers be dynamically balanced.

THE EFFECT OF VARIATION OF PITCH OF TWO PROPELLERS ON EFFICIENCY, ECONOMY AND ON OPERATION IN COMPARISON WITH SIMILAR SHIPS.

Case. I.—A twin screw destroyer.

The commanding officer of this destroyer reported that it was found that

(*a*) From 5 to 8 pounds per square inch more steam pressure was uniformly required for the starboard (shorter shafting side) engine, other things being equal;

(*b*) During several four hour tests steaming abreast in which she made the same number of turns as her sister ships, she steamed approximately two miles farther through the water;

(*c*) When cruising in formation her record of miles steamed by revolutions would average 20 to 25 miles per diem less than her sister ships;

(*d*) Investigation then disclosed that the pitch of the starboard propeller was 10 feet 2.35 inches, instead of 9 feet 11 inches, as designed for this group of vessels;

(*e*) The propeller otherwise functioned perfectly.

Assuming that each of the two propellers of this ship operated so as to give the speeds corresponding to 170 R.P.M. given on the standardization curves of two destroyers, one having two propellers of the smaller pitch, the other having two propellers of the larger pitch, it is found that with

9 feet 11 inches pitch the corresponding speed is 15 knots.

10 feet 2 inches pitch the corresponding speed is 15.8 knots.

The average is 15.4 knots.

In four hours the difference 0.4 knot will check the statement of experience made in (b) above.

The efficiency (in its true sense) of operation of the destroyer with the propellers of different pitch might vary slightly from that of her sister ships with propellers of the designed pitch, but it is believed that the difference would be within the probable errors of measurement on trials as usually run. And it is conceivable that at some speeds and in some ships the combined machinery propeller efficiency would favor the unbalanced arrangement.

The effect which causes most concern in such cases, and which brought forth the report mentioned above, involves comparative performance of a group of sister ships.

When the allowance of fuel is based on revolutions, the ship with one or more propellers which have greater pitch than that which determines the allowance is handicapped adversely, while the ship with propellers having smaller pitch than the standard is handicapped favorably.

NO. 1.

THE TREND IN NAVAL ENGINEERING.

SEARCHLIGHT MIRRORS—MANGIN VERSUS PARABOLIC.

By C. HUEY,* CIVIL MEMBER.

The standard equipment for searchlights of twenty years ago was the *Mangin* mirror, so named from the inventor, Col. Mangin, an officer of the French Army. This device is a concave-convex blank silvered on its convex side. The two surfaces are spherical in shape, but of different radii, so proportioned that the light in transmission and reflection is condensed to an approximately parallel beam. This type of mirror is reasonably efficient and for a long time was considered satisfactory. The grinding of the surfaces is fairly easy, as each is a true spherical section. At the time of the introduction of the *Mangin* mirror, it was considered an optical masterpiece. However, there were serious limitations. The compensation of the surfaces is designed for a point source of light. When used with a carbon-electric arc, the crater of which is comparatively large, the beam spread is too great for practical service for long distance projection. This greatly limited the usefulness of this type of mirror. Further, due to the necessary difference in radii of the two surfaces and the desirability of having the section at the center of such thickness as to be mechanically strong, these mirrors were very thick at the edges, thus producing a bulky and heavy product. In the 30 inches diameter size, the mirrors were so heavy, with edges being about

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EDITOR'S NOTE. This is the first of a series of articles by Mr. Huey showing the trend in naval engineering with respect to different materials and kinds of apparatus. The next subject will be storage batteries, nickel-iron-alkaline type vs. lead-acid types.

* Material Engineer, U. S. Navy Yard, New York, N. Y.

2 1/4 inches thick, that further advance in sizes became prohibitive. This practically limited the possibilities of searchlights to sizes not exceeding 30 inches mirror diameter.

Development of machinery and the optical grinding art finally resulted in the *parabolic* glass mirror. The parabolic mirror is far more expensive to manufacture than the *Mangin* mirror, but the introduction of the *parabolic* design, made possible the tripling of the maximum size practicable with the *Mangin* mirror. The *parabolic* glass mirror is composed of two *parabolic* surfaces, the curves of the front and back surface being compensated for the refraction of the glass, to produce a parallel beam from a point source of light at its composite focal center. The glass thickness varies slightly in design, but to all intents and purposes its thickness is uniform. The added efficiency, reduction in weight, and practicability of parabolic mirrors of large diameters, resulted in the *Mangin* mirrors becoming obsolete for searchlights of sizes over 12 inches. The *parabolic* mirror is now standard in the Navy for searchlights from 18 to 60 inches diameter.

MANGIN MIRROR DESIGN.

In the basic design of the *Mangin* mirror, consisting of two spherical surfaces, the two surfaces can be analyzed separately as to their functions. Referring to sketch Figure 1 is a plane reflecting sphere, with a point source of light placed at its focal center. It can be seen that all light emanating from this focus toward the reflecting surface will be reflected back through the focus and emerge as a beam with an angle of spread equal to the solid angle subtended by the reflecting surface. This would be far from any conception of a projected beam, the intensity of which would decrease directly as the square of the distance. This design would be useless for projection.

In Figure 2, a second spherical surface is added, forming a compensated lens, the radius of the added transparent face being so designed as to furnish the necessary refraction of the light passing into it, as to alter the course of the ray impinging upon the reflecting surface, so that upon emerging again from the transparent surface after reflection, the emergent ray is perpendicular to the cord of the arc of reflecting spheroid.

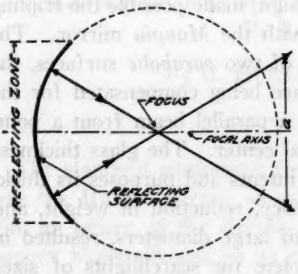

FIG. 1

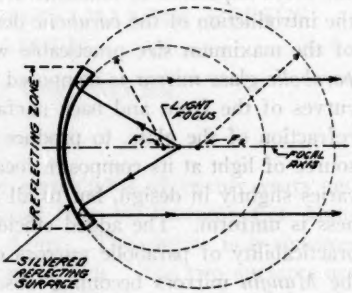

FIG. 2

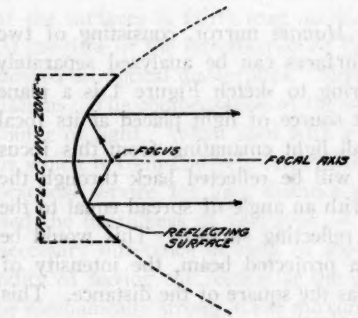

FIG. 3

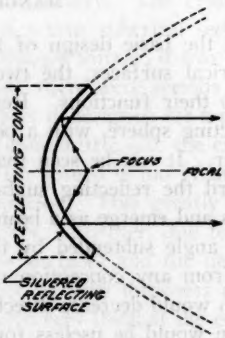

FIG. 4

In this way, by a combination of two spherical surfaces, the effect of a meniscus lens is produced, corrected for a parallel emergence of all rays emanating at the focal point of the reflecting surface. This correction only holds, however, for a true point source of light.

PARABOLIC MIRROR DESIGN.

In the basic design of the parabolic reflector, again the analysis can be made by considering each individual surface as to its function. In Figure 3, the reflecting parabolic surface is inherently a corrector of all reflecting rays emanating from its focus, from their law of squares dispersion, to a true parallel reflected ray, the rays from all points on the reflecting surface being parallel to the focal axis of the paraboloid. The polished parabolic surface can, therefore, be used with a point source of light to produce a parallel beam without any means of compensation, and this is the general form of all metal parabolic reflectors used principally in astronomical instruments.

The Navy parabolic glass mirrors can, therefore, be considered a silver parabolic surface, covered with glass to prevent corrosion and give mechanical strength. Metal reflectors with *direct* reflecting surface for searchlight use have not to date been successful, due to difficulty of accurate forming and to corrosion effects, which in a short time destroy the reflecting surface. Heat, also, of intensity produced by the arc as a source, causes warping, thus destroying the parabolic shape. However, there has been recent activity in further development of the metal mirror which if perfected will no doubt supersede the fragile glass mirrors for Naval Service.

The difficulties above have at present been surmounted by silvering a parabolic glass surface on the convex surface of a ground blank, the transmitting concave surface of which is a second parabolic surface. The focal lengths of these two parabolas is slightly different, and the light, from a point source, Figure 4, entering the first surface, is slightly refracted by a predetermined amount, but to such an extent that when returning through the transmitting surface, the double refraction encountered will set the emergent rays parallel to the focal axis. This analysis, as in the Mangin blank, also holds only for the point source of light.

DISCUSSION OF RELATIVE MERITS IN SERVICE.

There is no existent point source of light, and, therefore, while the merits of the Mangin and the parabolic forms of mirrors would appear the same, actually they are far different in practice. All light sources have a finite diameter, and the reflector, therefore, must be compensated to partially correct for light rays emitted from the source of finite diameter at plane of the focal center of the reflector. The reflector may be said to act as a magnifying lens, enlarging the image of the light source and projecting it out to a target. The most useful form, therefore, is the one which can be readily and accurately made to produce the least distortion of this image, as gauged by divergence of rays of the beam.

Spherical surfaces, when corrected for this condition become involved aspheric curves, very difficult to produce. Therefore, while the spherical mirror is easy to produce in its theoretical form, it is prohibitive in its practical form, and only the practical form is useful.

On the other hand, the parabolic form is useful for projection of rays slightly off the focal axis. Further, by employing the aid of refraction principles, the parabolic mirror can be fairly well compensated to produce efficient results within reasonable cost.

In the Navy parabolic mirror, the glass is not of uniform thickness over its surface, and is not a true uniform parabola on the convex surface, as this surface is varied in form to produce the desired correction of the rays by refraction. The variance in thickness, however, is very small, and therefore unlike the Mangin mirror, the weight increases approximately with the area. Large diameter mirrors of relatively light weight are thus produced, a fact not possible with the Mangin or spherical design.

Thus, so far as the Navy is concerned, the trend at present is towards parabolic mirrors for all sizes of both the incandescent and the arc types of searchlights.

THE BUILDING AND INSPECTION OF A BOILER.

By Lieutenant W. A. Brooks, U. S. N., Member.

After it has been decided to lay down a new steam-propelled vessel, one of the first things to be done is to arrange for the building and delivery of the boilers. Present practice calls for the boilers to be "built into" the ship, that is, the boilers are located in the fire rooms before construction of the vessel has progressed very far. This means that the boilers must be ordered, at times, even before the keel of the vessel is laid, for it takes, normally, from eight months to a year to complete a set of boilers. And of course before actual construction can be begun, proposals must be sent out and time allowed for the leading boiler manufacturers to make their bids, and for the successful bidder to be notified and the contract signed.

If for a direct Navy Department contract (as for vessels being built in Navy Yards), the proposal or schedule is sent out by the Bureau of Supplies and Accounts, although of course the engineering features have been determined by the Bureau of Engineering. The information given on the schedule, on which the manufacturer bases his bid, may be expected to include data as to the following:

*(1) Type of boiler.

(2) Limiting over-all dimensions as to height, width, length.

(3) Pressure and superheat.

(4) Capacity of boiler in pounds of steam per hour.

(5) Limiting air pressure that may be used.

(6) Rate of oil-burning allowed in pounds of oil per hour per square foot of generating surface. (This will determine the amount of heating surface needed.)

* As nearly all naval vessels now in commission, and all new construction with the exception of Light Cruisers Nos. 32, 34 and 36 (which are to be equipped with sectional Express boilers of the round-header type) are equipped with Express boilers of the three-drum type, this article will deal especially with this type, although many of the following remarks apply equally well to other types.

(7) Efficiencies to be guaranteed.

(8) Limiting weight of boilers including water weights.

(9) And various items such as type of fuel, spare parts, evaporative and weight equivalents, penalties, payments, etc.

The manufacturers having made their bids on the basis outlined above, the bids are opened, evaluated and the award made to the successful bidder. The contract having been signed, it now becomes necessary to draft the general and detail drawings and submit them for approval.

In the case of vessels built by private shipyards, the yards themselves arrange for the purchase of the boilers, but of course they are restricted as to type, pressure, superheat, etc., by the terms of their own contract with the Navy Department for the building of the vessel. Some yards manufacture their own boilers, but such are at present in the minority.

In any case, the general and detail drawings (known as Type B drawings) are forwarded to the Bureau of Engineering for approval *via* the Inspector of Machinery concerned; that is, either the Inspector at the shipyard, or the resident Inspector at the boiler works, depending on whether or not the contract is let to a private yard or to a Navy Yard. It is the Inspector's duty to check the drawings carefully to see that they are in accordance with the General Specifications for Machinery, the Bureau of Engineering Standards and the contract. This involves such points as tubes, tube holes, riveting, shaping of sheets and heads, flanges, pitch circles, rolling tubes, thickness of casings, insulating material, furnace brickwork, arrangement of fittings and in general all features of construction, including leaflet specifications entered in the Bills of Material. The Inspector will confer with the contractor as to any discrepancies found, and by mutual agreement most of the discrepancies will be eliminated. In any case, any discrepancies still remaining will be commented on by the Inspector in his letter forwarding the drawings to the Bureau. The Bureau, in its action on the drawings, will either approve the drawings or indicate what changes it will require the contractor to make. Copies of approved drawings are retained by all parties concerned. Subsequent alterations to approved drawings are either passed on

by the Inspector concerned, or by the Bureau, depending on the magnitude of the alteration.

With approved drawings on hand, the boiler manufacturer proceeds to order the boiler material. Copies of all purchase orders are furnished to the resident Inspector, who checks them against the approved drawings and, in cases where applicable, the Acceptable List also, as, when material appears on the Acceptable List, such material must be ordered from manufacturers whose material has passed prescribed tests and is found on this list. The order having been approved by the Inspector, it is forwarded to the Inspector of Naval Material of the district in which manufacture is to take place. The latter officer then accomplishes the inspection and forwards shipping reports, certifying the material, to the Inspector with whom the order originated.

The inspector at the boiler works thus finds himself with all the materials of construction on hand, fully inspected at the place of manufacture, with the exception of certain commercial material which does not require full inspection, and which he himself will inspect as to dimensions, workmanship, surface defects, etc.

Probably the most important material entering into the construction of a boiler is the boiler plate from which the drums are made. The leaflet specification lists three grades of boiler plate, but Grade B is the one most commonly used. This plate must be made by the open hearth process. Tensile strength may vary between 55,000 and 65,000 pounds per square inch, with the yield point at least half the tensile strength, and the elongation in eight inches must be at least 22 per cent. The plate must be flat, free from welds, buckles, brick or scale marks, slag or other foreign substances, brittleness, hard spots, scabs, laminations, snakes or other injurious defects. It must also pass a bend test by being bent cold 180 degrees around a pin whose diameter depends upon the thickness of the boiler plate.

With all the material on hand, shop orders are issued by the manufacturer and the actual work of fabrication begins. The first thing to be done is to plane the tube sheets, wrapper sheets, butt straps and drum head plates to the required dimensions. All the above parts are required to be bent to shape while hot, but in some instances exceptions are made for the wrapper sheets and butt

straps, and they are then bent cold. In either case the parts are formed to shape in hydraulic presses.

After being bent to shape, the tube sheets, wrapper sheets and butt straps are assembled in position and the rivet holes drilled. In this connection it should be noted that it is forbidden to punch rivet holes. After the holes are drilled, the parts are disassembled and all burrs removed, the parts sandblasted, reassembled, and while held accurately in position, all rivet holes are faired by reaming. The drum shell is then ready for riveting, which is done by hydraulic presses or bulls. Pressures used and times of holding same, as required by the General Specifications, are as follows:

for 1¼-inch rivets, 80 tons pressure, held 24 seconds.
1-inch rivets, 65 tons pressure, held 20 seconds.
¾-inch rivets, 50 tons pressure, held 15 seconds.

Drum heads are flanged while hot, and as required, pierced for manhole—with flange turned in for manhole seat—and bumped for water gauge fittings and feed connection. The outside of the drum heads and the inside of the drum shells are machined to fit each other, drilled while assembled, disassembled, burrs removed, sandblasted, reassembled, reamed and riveted. Drum seams are required to be double or treble riveted, except for the water drums, where single riveting is permitted. All seams and rivets are lightly calked on the inside, but no calking is permitted on the outside. With the drums assembled and riveted, they are given a hydrostatic test of one and a half times working pressure, and must be absolutely tight at this pressure.

Drums are checked for dimensions, roundness and straightness, and are then laid out for drilling. Openings for safety valve and main steam nozzles, downcomers, retubing handholes, bottom and surface blow valves, try cocks, etc., are first drilled. Then the tube holes are drilled in both steam and water drums by means of large multiple drill presses. This drilling will leave circumferential grooving in the holes, and probably a shoulder on the long side. To remove the shoulders and a part of the grooving, the holes are twice reamed, first with a rose reamer and next with a fluted reamer. Some grooving will still remain, but will do no harm unless it is radial or spiral; in fact, the circumferential grooving

will actually aid the tube in holding, after the tube is expanded in the tube sheet. After the reaming, the edges of the holes are carefully rounded by hand or machine tools, both inside and outside, in order to prevent cutting or scratching the tubes in the tubing process. Tube holes are permitted to have a positive tolerance of .015 inch for 1-inch tube holes and .019 inch for 1¼-inch tube holes. These tolerances are checked by means of "go" and "no go" gauges.

The water drums are now ready to receive the saddles. The drums are carefully leveled and centered, and the saddles fitted. This job must be carefully done in order that the boilers may fit the foundations in the vessel.

The drums are now ready to be set for tubing. Heavy foundation frames of structural iron are prepared to receive the water drums, which are bolted down to the foundation by means of the saddles. The water drums must be carefully leveled, with center lines parallel to each other and in exact location with respect to each other. Special cast iron erection frames are then clamped on, with fore and aft and diagonal braces to hold them in position. Then the steam drum is placed in cradles at the top of the frames and accurately located by means of heavy set screws which screw through the frames. When this drum has been leveled, centered and angled with respect to the water drums, it also is clamped in position. Superheater supporting guides are welded to the drums, and the boiler is now ready for tubing.

Boiler tubes may be either cold drawn or hot rolled, but in either case must be seamless. If cold drawn, tubes must be annealed as a final process. Tubes must be straight and free of all defects. The defects to be particularly avoided are tears, snakes, slivers, injurious scratches, rings, seams, pits and sinks in cold drawn tubes; and slivers, scratches, seams and scale pits in hot rolled tubes. A tolerance of 10 per cent over and nothing under the calculated weight is allowed. The finished tube must be circular within .02 inch and not less than the gauge specified. A tolerance of ±.010 inch diameter is permitted for tubes of not more than 1¼-inch diameter. Where working pressures do not exceed 400 pounds, the specified thickness of tubes is .095 inch for 1-inch tubes and .109 inch for 1¼-inch tubes. All tubes are inspected

at the place of manufacture as to the above considerations, and given specified flattening, flanging and expanding tests; and in addition are each given a hydrostatic test of 1500 pounds. In addition to the factory inspection, all tubes must also be inspected for surface defects immediately before installation in the boiler. Their ends are cropped to the exact length desired, rounded, polished for a distance of about five inches from each end and are then bent to the required radius or shape.

The tubes having been prepared as above for installation, they are inserted in the tube holes, radius or shape checked, end clearances fixed, and the ends expanded into the tube sheets by the parallel-rolling method. This method consists of using a tapered mandrel and tapered rolls of such dimensions that the result is a tube wall uniformly reduced in thickness, with parallel sides. In the taper-rolling method, formerly used, one part of the tube was reduced in wall thickness more than another part, tending to create a fin inside the tube where the expanding stopped; prolonged over-rolling might result in actually cutting the tube in two at the inner edge of the tube sheet. Another advantage of parallel-rolling is that a longer seat is produced, and hence there is less danger of leaks developing or of the tube pulling out. After the expanding is completed, the tube end is belled from 1/16 inch to ⅛ inch by means of either a drift or a belling roll. A few tubes will be found split after the rolling and belling, and these are cut out and replaced at once.

If downcomers are a part of the design (and the present General Specifications require them—to be approximately equal, in cross-sectional area, to the effective area of the fireside rows of tubes), they are bent to shape, cut to length, and rolled and belled into the drums. Several successive expandings with each set of rolls slightly larger than the one preceding will likely be found necessary in order to obtain a good seat for these large tubes.

After the generating tubes and downcomers are installed, drum openings are closed and a hydrostatic test pressure of one and one-half times working pressure is applied. It is likely that some leaks will appear, either due to defects developed during the bending of the tubes, or to insufficient expanding. Defective tubes are cut out and renewed, and tubes leaking around the tube sheets are

given a light re-rolling. The tests are continued until the boiler is absolutely tight for a considerable period of time, in order that no small leaks may be overlooked.

Superheat is now reappearing in the latest Navy boilers. The superheater, as usually built, is composed of the superheater boxes, tubes, baffles and supports. The boxes are made by taking very heavy round tubing, squaring it and drawing out necks for the flanges to which are bolted the connections for the wet and superheated steam. Plugs are welded into the ends of the boxes in order to close them. The boxes are then drilled for the tube holes and hand holes. The hand holes are made oval in a special machine, and faced for the hand hole seats. The necks on the boxes are then expanded into the grooved flanges, and either welded or beaded over at the top, the flanges then being faced. The superheater is tubed by expanding the tubes into the tube sheet, the tubes being held in position by passing through a support or guide plate, in which holes slightly larger than the outside diameter of the tubes have been drilled. After this, the ferrules or baffles are installed in the boxes or tube ends as called for, their purpose being to obtain equal steam distribution in the superheater tubes. The hand hole plates are next fitted, inlet and outlet connections blank-flanged, and the superheater given a hydrostatic test of one and one half times working pressure in order to check the tightness. After this test has been successfully passed, the superheater is installed in the boiler.

The next step is to install the internal fittings, that is, the dry pipe with safety valve and superheater connections, the feed pipe and its connection, surface blow pipe and connection, baffles and hangers. Next, the manhole plates must be checked up. When properly centered, there must be no more than 1/16 inch clearance between the rim of the manhole and the inturned flange of the drum head. Also, the face of the seat and the seat of the manhole plate must be parallel within a tolerance of $\pm.003$ inch, without the gasket in place. Finally, each manhole dog is carefully fitted and the dogs and plate indelibly marked to show to what hole they have been fitted.

After this, the boiler is given another hydrostatic test of one and a half times working pressure to insure tightness of all joints

and parts. Following this, the pressure parts are oiled, inside and outside, with a preservative mixture. The mixture giving the best results consists of 50 per cent Japan drier, 30 per cent gasoline and 20 per cent corn oil. This mixture dries quickly, and because of its varnish-like consistency, is an excellent preservative.

With the pressure parts O. K., the work of putting on the lower side casings, brick pans, fire front, back casing, upper side casings, front casings, etc., begins. Angles are first welded to the steam and water drums, these angles serving as anchors from which the casings, brick pans, etc., receive support. The fire front or front plate, which carries the burners, is made from 1/2 inch plate, but the remaining plates are not over 1/8 inch in thickness, except for the brick pans, which are at least 1/4 inch thick.

Casing panels are used to cover the front, sides and back of the boiler in the wake of the tubes. A boiler casing panel consists of an inner wall of steel plate, suitably flanged all around, against which is fitted a course of uncalcined diatomaceous earth bonded with long fiber asbestos, at least 2 1/2 inches in thickness, over which is fitted 1/32 inch galvanized steel plate. Sheet asbestos inside the flanges prevents the galvanized sheets from making contact with the flanges—this to reduce the heat transfer. Asbestos millboard, 1/4 inch thick, is used to line the inner surfaces of all casing panels which are likely to encounter high temperatures. All joints are rendered air-tight by inserting metal-covered asbestos strips between the casing flanges.

The present approved method of laying the brickwork of a boiler is as follows:

(1) For the floor, a 1 inch course of insulating material is laid against the brick pan. Over this is laid a 2 1/2 inch course of calcined diatomaceous earth brick of standard size. Over the two insulating courses are laid two courses of 1 1/4 inch standard split fire brick at right angles to each other. A 1/16 inch opening is required between bricks and a 1/4 inch opening between outside bricks and the side walls, all openings being filled up with suitable loose, dry fire clay.

(2) For the side and back walls, a 1 inch course of insulating material is placed next to the casings, then a 2 1/2 inch course of calcined diatomaceous earth brick of standard size laid on edge, and lastly, a 4 1/2 inch course of refractory fire brick of standard size and approved type.

(3) The front wall is built in the same manner and of the same materials as the side wall, except around the oil burner openings, where either plastic refractory or special shapes are used for building up the burner cones. If special shapes are used, the space between the special shapes and the regular fire brick will be filled in with plastic, which will also be used to finish off walls, smooth up courses and fill up crevices caused by intersection of the metal parts with the brickwork. It is customary, however, not to lay up the plastic, nor put in the cone brick until just before the boiler is ready to be lighted off, as it is essential to thoroughly bake the plastic firebrick soon after its installation.

The soot blowers are next fitted and installed. The soot blower elements, running the length of the tube banks, are fitted with expanding nozzles, to increase the steam velocity. The location of the nozzles is carefully worked out so that steam does not impinge directly on the nearest row of tubes, but is directed between the tubes of that row. The intention of the above is of course to prevent erosion of the tubes nearest the steam jet. The soot blower heads are attached to the boiler casings, which are reinforced at these points, and the soot blower elements are carried in guides or bearings clamped to the tubes. Elements are made of special heat-resisting alloy, of calorized steel, or of plain steel, according to their proximity to the furnace. The soot blowers installed in all the latest boilers have elements that can not only be rotated but can also be moved fore and aft a definite amount, usually equal to the tube pitch.

The oil burners are usually installed after the boiler is in the vessel. The burners might be damaged in handling the boiler, and they also add weight which can be avoided. The 10,000-ton class of light cruisers are all fitted with Cuyama-type burners, twelve, thirteen or fourteen to a boiler. The burners are equipped with three sizes of sprayer plates, intended for full power, cruising and port uses, respectively. The actual sizes furnished are

2908 or 3008 for full power, 3208 or 3908 for cruising and 4408 or 4808 for port use. In designing the boiler, the projected center lines of the burners must not be nearer than 24 inches to a side wall or furnace bottom, nor less than 30 inches from the nearest point of a tube bank; and the inner edges of the burner openings must not overlap. These conditions, in an Express boiler, will determine the size of the front plate, and hence, indirectly, the amount of furnace volume, since in most cases, when the above conditions have been fulfilled, the resultant furnace is actually larger than is absolutely necessary for good combustion.

Boilers, when completely assembled, are shipped, if possible, *via* inland waterways. Ocean shipment of such large units (they weigh approximately sixty tons) may result in damage to the boiler in case heavy weather is encountered. As assembled boilers can be shipped from the East Coast to the West Coast only *via* the Panama Canal, it is good practice to ship boilers in the "knocked-down" condition, and assemble same at destination, as was done very successfully in the case of the boilers for the *Chicago* and *Louisville*. However, when inland waterways can be utilized, complete assembly at the place of manufacture is considered preferable.

At some time before turning the boilers over to the operating personnel of the vessel they must be boiled out in order to eliminate the preservative with which they were coated before leaving the manufacturer's plant. If this were not done the result would be warped, blistered or burned-out tubes when the boilers were put in service, not to mention other complications along the path of the steam. If "corn oil" preservative has been used, the ordinary methods of boiling out with boiler compound and/or kerosene will not suffice. It will be found necessary to resort to the use of some proprietary compound, of which several are on the market, in order to eliminate all the preservative.

After the boiler has been installed in the vessel, and usually after the external valves and fittings have been assembled on the boiler, a hydrostatic test of one and one quarter times the working pressure is applied to determine if any leaks have developed as a result of moving and shipping the boiler. Also, a hydrostatic test at working pressure is applied for twenty-four hours to deter-

mine the pressure drop over that period, a drop of over 10 per cent being considered unsatisfactory. Following the satisfactory completion of the above tests, and of course after the remaining brickwork and oil burners are installed, steam is raised in the boiler and a steam tightness test at one and a quarter times working pressure is conducted for a period of at least one hour. If any leaks develop on this test they must be corrected before steam and water joints are lagged. Lastly, a smudge test of the casing is made, using a pressure of at least one inch of water. There must be only negligible leaks at this pressure.

The boiler having passed the smudge test, its complete inspection has been accomplished, and it is now ready to be turned over to the operating personnel of the vessel.

THE MATERIAL LABORATORY, U. S. NAVY YARD, NEW YORK.

By Commander F. J. Cleary, U. S. N., Member.

"There is *more than a grain* of truth in the statement that 'leadership is born in the research laboratory.' As a matter of fact, competition is met, new and highly profitable products and processes are developed and current high industrial quality is rigidly maintained and improved—all in the corporation's research laboratories. The present age of science and highly technical developments demand the best equipment and a highly skilled staff to carry on the all-important work in the laboratory. Today the large and dominating corporations are fully cognizant of the vital part which the laboratory plays in their future; and, most important from the investor's standpoint, such organizations are in the best position to spend large sums annually to adequately maintain the best of equipment and the most talented staff available." *

Under the control of the Navy Department there are three laboratories engaged in investigation, research and testing.

Two of these laboratories, the Engineering Experiment Station at Annapolis, Maryland, and the Naval Research Laboratory at Bellevue, D. C., are well known.

Inasmuch as the development, organization, facilities and work accomplished at the Material Laboratory, Navy Yard, New York, are comparatively unknown, this article has been prepared to bring to the attention of the Naval personnel the activities of this laboratory.

The Material Laboratory had its origin in two laboratories which came into existence many years ago at the Navy Yard, New York. primarily for local purposes. Those two laboratories were the Yard Electrical Laboratory and the Yard Mechanical Laboratory.

The Electrical Laboratory was originated about 1900, as a part of the old "Equipment Department" (later transferred to the Machinery Department), with six employees, rated as sub-inspec-

* "Buying Stocks on Leadership," W. B. K. Dove in Magazine of Wall Street, June 28, 1930.

tors, electrical, who conducted acceptance tests on electric cables, motors, generating sets, searchlights, rubber goods, canvas materials, and a great number of miscellaneous items of equipment. At that time, contractors supplying material to the Navy had little or no facilities for conducting tests to determine compliance of their material with the purchase specifications and consequently practically all acceptance tests were conducted after delivery at the Navy Yard. As time went on, contractors gradually purchased test equipment with the result that acceptance tests were transferred more and more to the contractors' works and conducted with the contractors' equipment and at the contractor's expense, except for the cost of supervision of the Naval inspection personnel. During this period, when radio was first becoming active in the Navy, a section of the Electrical Laboratory was expanded to provide for this rapidly growing field, until radio had become of such importance and so highly technical in nature that a Radio Material Section was established as a separate activity in the Navy Yard, under the jurisdiction of a Radio Material Officer. Also, at about this period, when gyro compasses became an established part of ships' equipment, a Gyro Compass Section was added to the Electrical Laboratory.

The Mechanical Laboratory was originated about 1900, as a part of the Hull Department, with the installation of one piece of equipment, a Riehle 75,000-pound screw, motor-driven tensile testing machine; for a short time the work of the Mechanical Laboratory consisted almost entirely in testing supplies delivered to the Navy Yard, but the Bureau of Construction and Repair early used this laboratory for Bureau tests and this load has continuously increased.

From time to time new testing equipment was purchased and special adapters and equipment made by the personnel of this laboratory, so as to expand the testing activities, until during the World War the personnel of this laboratory had grown to about fifty employees, the greater number of which were released after the cessation of hostilities.

In 1922, upon the reorganization of the Navy Yard, New York, and the establishment of an Industrial Department, the Electrical Laboratory and the Mechanical Laboratory were consolidated as

the Material Laboratory with an experienced officer of relatively high rank in charge, and the present organization was developed. While, as stated above, this laboratory primarily had its inception in local needs, its activities have so expanded that at present 90 per cent of its work is investigation, research and tests directed by the Bureaus and tests for the Bureaus' field inspection forces.

The Material Laboratory is divided into three main Sections: The Electrical Section, the Mechanical Section and the Gyro Compass Section. The Electrical and the Mechanical Sections are each immediately supervised by a material engineer, the Gyro Compass Section is immediately supervised by an officer of the rank of Lieutenant, who has had previous extensive experience with gyro compasses.

The present civilian personnel (71) of the Material Laboratory is composed of the following:

2 Material Engineers.
6 Associate Material Engineers.
1 Assistant Material Engineer.
7 Junior Material Engineers.
1 Metallurgist.
3 Senior Inspectors of Naval Material.
5 Assistant Inspectors of Naval Material.
41 Mechanics and Helpers.
3 Clerks.
1 Stenographer.
1 Messenger.

71 Total

The average yearly expenditures of the Laboratory amount to approximately $180,000.00, subdivided as follows:

	Fiscal Year 1930		
	Title G	*Title V*	*Total*
Bureau of Engineering	$ 7,497.00	$69,970.00	$77,467.00
Bureau of Construction and Repair	8,122.00	57,481.00	65,603.00
Bureau of Navigation	13,520.00	16,177.00	29,697.00
Bureau of Yards and Docks	1,394.00	.....	1,394.00
Bureau of Supplies and Accounts	5,522.00	.....	5,522.00
Bureau of Aeronautics	.....	2,000.00	2,000.00
Totals	$36,055.00	$145,628.00	$181,683.00

The Title G amounts listed above are all charged to determinate Bureau appropriations so that there is no part of the cost of the Laboratory lodged against Navy Yard expense (overhead).

In addition to the above regular expenditures, tests are conducted at the expense of civilian manufacturers, as authorized by the Bureaus, under the category of "Special Deposits," amounting to about $2,500.00 per annum.

The Material Laboratory is located in a three-story building in the Navy Yard, New York (Figure 1), and occupies all of the first floor and the greater part of the second and of the third floors of that building, or a total floor area of 43,800 square feet of actual working space devoted to Laboratory purposes (not including space taken up by corridors).

The Laboratory possesses a great amount of scientific and test apparatus, by far the larger part of which is modern. It is believed that some of this equipment is not surpassed in accuracy and value by equipment in any laboratory in the United States.

The great value of the Material Laboratory to the Navy lies in the fact that by its location in the Navy Yard, New York, the extension and practical application of the laboratory tests are conducted in the Navy Yard shops and aboard cruising ships, based on the Navy Yard, New York, where the results obtained can be supervised and checked by the laboratory personnel engaged in the tests. Farther, in being located in the center of one of the most extensive manufacturing and research localities in the country, there is a continuous exchange of visits and information between the personnel of the Material Laboratory and the personnel of manufacturing establishments and of research and scientific laboratories in the City of New York and vicinity.

The work of the Laboratory has been seriously hampered at times by resignations of skilled, laboratory-trained personnel, because of better paid opportunities in private establishments.

There follows a description of the various sections of the Laboratory, of the equipment, and of a few of the more important and valuable tests and experiments which have been conducted by the Laboratory in the past few years and which are under way at the present time.

THE ELECTRICAL SECTION.

This section investigates and tests the following:
(Items marked * are later described more in detail.)

Motion Picture Equipment.
*Sound Motion Picture Equipment.
General Announcing Systems.
Loud Speaking Telephones.
Ships Service Telephones.
*Illumination Equipment.
Illumination Glassware.
*Navigation Lights (Weather Resisting Glass).
*Protective Industrial Lenses.
*Aviators Goggles.
*Searchlights.
*Searchlight Mirrors.
*Searchlight Carbons.
*Non-Scatterable Glass.
Lenses.
*Optical Instruments.
*Storage Batteries.
Battery Relays.
*Dry Cells.
*Portable Electric Tools.
*Shock Proof Circuit Breakers.
*Arc Welding Sets.
*Carbon Brushes.
*Ventilating Sets.
*Salinity Indicators.
*Electric Logs.
*Insulating Materials.
*Insulated Wire & Cable.
*Engine Telegraph Systems.
*Revolution Indicators.
*Electric Refrigerators.
*Insulating Varnishes.
*High Voltage Resistance Materials.
Motors.
Motor Starters.

Generators.
Controllers.
Relays.
Fuses.
Switches.
Switchboard Measuring & Recording Instruments.
Electric Heaters.
Electric Galley and Laundry Equipment.
Detectors for Hydrogen and Other Inflammable Gases.
Etc.

For the purpose of specializing in the above work, the Electrical Section is divided into sub-sections as follows:

Light and Sound.
Battery.
Power.
Standard Instrument.
Miscellaneous.

THE LIGHT AND SOUND SECTION.

This section conducts research, investigations and tests (supplemented by tests aboard cruising ships) on all material having a bearing on illumination, sound, and optics, and their application to the Naval service.

All of the tests in this section have involved the purchase or development of special equipment by the use of which accurate instrumental determinations have been substituted for the former human determinations, which were only matters of individual opinion. Under these new test methods all data are in the terms of instrumental figures (oscillograms, response curves, load curves, etc.), thereby eliminating all chance of personal peculiarities and errors. It has been of interest, in connection with this method of instrumental testing to determine the wide variation in the acuteness of hearing of various members of the Laboratory force and visiting officers from ships and Bureaus, by determining within what range they could hear a pure sound note which was constantly changing its pitch (number of sound oscillations per second). The precision oscillator used for this purpose emits notes of from 30 to 17,000 oscillations per second. The best

acuteness of hearing of any one listening to the sound produced varied from a low of 30 to a high of 17,000 oscillations. Several of the personnel tested could not hear oscillations higher in frequency than 7,000 per second.

The section is equipped with the following scientific bench and portable apparatus for laboratory and field work:

One 80 foot bench Photometer (Figure 2) for measuring searchlight arcs (one of the largest of its type).

A compensated sound testing room 20 feet × 20 feet × 14 feet high (Figure 3) for the testing and development of sound apparatus, such as loud speaking telephones, buzzers, ship alarm signals, etc., and the latest application of sound in connection with the investigation and development of satisfactory sound motion picture equipment for use aboard ship. The walls, ceiling and floor of this room are lined with several layers of sound absorbing material, as described more in detail below.

The electrical equipment of the sound room consist of the following:

(a) Two Condenser Microphones of the studio type and a multiplane rotator; one microphone, mounted on the rotator, is used for making sound readings on speakers or other devices; the other microphone, mounted on a stand, is used for making sound pressure determinations. Both microphones are connected to a three-stage amplifier of special design and either microphone can be used with the amplifier for the measurements desired. The output of the amplifier is carried to a delicate thermocouple milliammeter. (A portable amplifier with all batteries, etc., self-contained, is used for field observations, having been recently used aboard the U. S. S. *Texas* to obtain field data relative to the installation of sound motion picture apparatus on board ship.

(b) *A Precision Oscillator* (or sound reproducer) of the beat frequency type, with a compensating output circuit of special design for matching the loads and with a power output of eight watts, producing a pure sine wave, is used as a source of A. C. power of known characteristics for testing sound amplifiers and loud speakers. A part of this equipment is a cathode ray oscillograph tube (Figures 4 and 5) especially connected to a sweep circuit. It produces the still image of 1/2 the wave on a 2 inch

square area, of any wave form at frequencies varying from sixty to one million cycles. This device is used to analyze the wave distortion or introduced harmonics of amplifiers and can be used either visually or to make a photographic record. This precision oscillator, in addition to its use in the sound room, can be used for any oscillographic work where the system produces recurring phenomena.

Two Hilger Radiometers, one equipped with gold reflecting mirrors and rocksalt prism for the investigation of the infra-red spectrum from 700 to 10,000 milli microns wave lengths, and one equipped with quartz prism and lenses for the investigation of the visible and ultra-violet spectrum from 700 to 200 milli microns. These two instruments form a single set, and are designed for either visible observations or quantitative analysis by use of a thermocouple and a galvanometer. They can be used for radiant energy analysis of emission or absorption in liquids, or reflection from solids or liquids. This equipment is so installed that it can be readily applied to problems of suitability of material under contract or for investigations of unknown material. An interesting practical application of these radiometers was in connection with determining the percentage of dangerous infra-red rays transmitted through welder's goggles (referred to farther on in the text).

One Hilger sector-type quartz Spectrograph fitted with slits, quartz lenses, a quartz 60 degree Cornean prism, quartz mercury lamps, color filters, fluorescent screens, and photo plate holders. It is designed to photograph the entire visible spectrum from 700 milli microns to 180 milli microns on two settings of the arc. It is also fitted with a neutral tint wedge for determining the relative transmission of spectral sections for the investigation of solids and liquids by transmission or solids by reflection.

One Hilger constant deviation type Spectrophotometer fitted with shutter, crosshair eye pieces, collimators with micrometer slits and a lummer brodhun cube for photometric field. The optical system is of glass, the constant deviation prism being of a specially dense glass. It is designed for either visible comparison of the sources under investigation, separately or for photometric comparison. It can be used, also, as a spectroscope or spec-

trometer for visual observations of quantitative analysis by using a thermopile and galvanometer. This instrument is suitable only for visible spectrum work.

Two Refractometers, one a Bausch & Lomb "Abbey" type, the other a Hilger "Pulfrich" type. Both instruments are used to measure refractive indices of solids and liquids. The "Pulfrich" is a high precision instrument used for monochromatic determinations and for spectrum dispersion determinations of either liquids or solids. The Bausch & Lomb "Abbey," not being a precision instrument, is used for checking and inspection work.

One Transmission Photometer of the "balanced field" type, designed and built by the Laboratory, is used for measuring the white light transmission of clear and colored materials. The photometer head is a Martens Polarization photometer, arranged in conjunction with screens, sources of illumination and controls, so that the transmission of light varying from as low as .0001 per cent and as high as 100 per cent can be measured within close limits of accuracy. This device is used for testing the light transmission of welder's lenses, welder's helmet glass, aviator's goggle lenses and colored running and signal light lenses. The instrument, in conjunction with spectral equipment, was used for the development of lenses for sun protection and for arc protection.

Three Portable Photometers (two Macbeth Illuminometers and one Sharpe Millar Photometer) are used for measuring the intensity and distribution of light and for checking the effect of lighting systems. They have had many applications; among them, target illumination intensity, searchlight testing, illumination of ships compartments, artificial and natural interior illumination of buildings, etc.

Among the important investigations and tests conducted by this section are the following:

Sound Motion Picture Equipment. An extensive investigation and tests have been conducted of various sound motion picture equipment and the feasibility of installation aboard ship.

In connection with this investigation, it should be kept in mind that for several years past, commercial interests, with the tremendous technical facilities and the great financial backing at their disposal, have been working constantly on the development of the

scientific and instrument side of sound motion pictures. It was not until about August 1, 1929, that the Material Laboratory was notified unofficially that it was necessary for the Navy to go to sound motion pictures and that the Laboratory would be called upon to develop test procedure and specifications to obtain satisfactory equipment for the Navy afloat. At that time there were no test procedure and no suitable test apparatus in the Laboratory. It was necessary first for the Laboratory force to investigate suitable test apparatus, purchase, obtain delivery, set up, and become familiar with the use of the delicate and special apparatus that was found necessary to conduct satisfactory tests on this new and extremely complicated technical material.

After the completion of that preparatory work, extensive tests have been conducted by the Laboratory personnel aboard the U. S. S. *Texas* under actual sea conditions for four months and in the Laboratory under laboratory conditions, to develop a sound motion picture apparatus that could be satisfactorily shown under the same steaming conditions aboard ship as were the silent pictures. That has been accomplished and the tests conducted and specifications prepared covering such equipment have insured that the Navy will purchase and install aboard ship sound motion picture equipment which will be entirely satisfactory to the personnel afloat.

The tests at sea comprised the determination of the necessary fundamental requirements of ships' sound movies, the proper location of speakers, the sound pressure over the deck necessary to produce the desired results under sea conditions, the prevention of interference due to radio traffic, the effect of gunfire on apparatus and the necessary steps to be taken to limit damage to a minimum, and the necessary precautious to be taken to protect apparatus against sea air and dampness.

The apparatus used aboard the U. S. S. *Texas* was partly built by the Laboratory especially for this purpose. It comprised a standard broadcast microphone, calibrated in terms of sound pressure (dynes per square c. m.) and a suitable amplifier of such characteristics that the microphone response would not be affected by distortion in the amplifier. These data, not obtainable from any known source of information, were necessary to the makers

of apparatus and for the purpose of specifying the power desired on various types of ships.

Laboratory tests were conducted and are still active, comprising an analysis of the sound motion picture apparatus involving the mechanical parts of the projector, the photo cell, gain controls, amplifier characteristics and loud speaker characteristics, including material, electrical and acoustical performance.

In this investigation, standardization of integral parts has been attempted with marked success. The amplifiers are required to show flat electrical response to all frequencies from 30 to 7000 cycles (which covers the range of the human voice and the range of all musical instruments for entertainment purposes). This permits readily matching replacement of parts by purchase under competition in the open market, as any good photo cell and any good speaker of proper impedance can be used with such amplifiers. It also assures interchangeability of parts of the equipment between battleships and cruisers, permitting the carrying of a minimum of spare amplifier units, speaker units, photo cell units and vacuum tubes on repair ships or at shore stations.

In testing this equipment, unusual if not special apparatus and equipment has been found necessary as already described.

FIGURE 3—COMPENSATED SOUND TESTING ROOM.

In measuring the sound frequency and sound volume response characteristics of a reproducing apparatus for the conversion of energy into intelligible sound, the present method used is based on the measurement of the air disturbance produced by the reproducer and the conversion of these data either to absolute pressure values or to comparative values to an arbitrary standard base.

The apparatus employed in this work consists of a source of power which will produce alternating current of a perfect sine wave form at the desired frequency. This device, usually an oscillator, may be of the variable frequency type, timed by a carefully calibrated scale, or where single frequency signal notes are desired, by a crystal controlled oscillator. The type used for the measurements of voice or music reproducer testing is the timed frequency type with a range of frequency to cover the sound spectrum from 20 to 16,000 cycles. The type used in the Material

Laboratory was designed and built by the General Electric Company and is of the beat frequency type, using two radio frequency oscillator circuits, one timed over a relatively narrow range, and by heterodyning these two oscillators, a resultant audio frequency note is produced. This output from the oscillators is amplified through carefully designed circuits and permits a power output of about 8 watts. Matching compensators are provided so that the impedence of the load can be closely matched to make the optimum power at all frequencies available. This apparatus is to all intents a precision source of constant power at all desired frequencies.

The actual measurements are made by the use of a microphone (mounted on a multiplane rotator, Figure 3), the output of which is suitably amplified to produce power sufficient to operate a low scale thermo milli ammeter. A broadcasting type condenser microphone made by R. C. A. is employed, feeding into a six-stage resistance coupled amplifier. The output of the amplifier is measured in milli amperes. For comparative readings of sound response, the ammeter readings are plotted direct. For actual sound pressure readings, the microphone is calibrated in terms of milli amperes per bar (dynes per square centimeter) pressure on the diaphragm of the microphone.

This combination of microphone and oscillator comprises the equipment required for making sound frequency and sound pressure (volume) response of any type of sound producing equipment.

This equipment can also be used for making sound characteristic readings of a compartment by attaching in place of the milli ammeter a string galvanometer oscillograph with photographing attachment. With this equipment, the duration and decrement of the sound can be recorded for any frequency. In this set up, a reproducer is operated from the oscillator, producing notes of the desired frequency. By a system of relays, cutting out the speaker and turning on the oscillograph film in proper time sequence, a photograph of the sound decay, showing resonance or echo and the time and rate of total absorption, or the sound period, of the room can be definitely determined. This equipment can be made reasonably portable so that investigations of compartments in general can be made.

The compensated sound testing room, used in conjunction with the testing of reproducers and signal apparatus, must be classed as a part of the apparatus. As explained above, the sound, in terms of air pressure, must be transmitted through the air space separating the reproducer and the microphone. The air naturally must be static within this space, in order that the resultant response of the microphone will be truly the characteristic of the reproducer action. The microphone will record any air disturbance of changing pressure (sound), and any disturbance such as extraneous noises will interfere with the results. The disturbing sound may be caused by external noise, or it may be caused by reverberation or echo. It is, therefore, necessary that the room be free from noise, drafts, or reflection of the propagated sound.

The ideal condition of making sound measurements is out of doors, with reproducer and microphone located well above the ground, remote from walls and in still air conditions. For obvious reasons, it is apparent that out-of-door testing, where continuous testing is under way, is not practicable. Therefore, the sound damped room must be used. The damping of the room must be so accomplished as to render its characteristics equivalent to the out-of-doors characteristics, within practical limits.

The damping against reflected sound is accomplished by loosely hanging drapery on ceiling and walls and covering the floor with heavy carpet. The drapery is of such material that sound will be partly absorbed at the surface and partly transmitted through the weave. By hanging the drapes in several layers, with an air space between layers, sound reflection is reduced, and the time of sound decay in the room is shortened.

The sound proofing to exclude external noise is accomplished by building two rooms within the room selected. Each of these room walls is of one-inch sheet compressed cork. The outer wall is spaced with a one-inch clearance all around ceiling and walls from the building walls. The building floor is lined with one-inch cork. The inner cork wall is spaced with a one-inch clearance from the outer cork wall. This construction presents two complete absorbing medium layers and three surface reflectors. The cork walls are outside the drapes and any sound from the inside which

passes the drapes is partly transmitted and absorbed by the cork and the part which is reflected back from the cork is again intercepted by the drapes.

When thus constructed, this room becomes essentially a part of the sound testing equipment and apparatus. It is the air link or chamber between the reproducer under test and the calibrated microphone.

Even with this elaborate construction, it is not possible to have the room completely sound proof nor completely absorbent at all sound frequencies. However, if the room is considered as part of the testing apparatus, its characteristics are constant and are added to those of the apparatus, and the characteristics of the room can be corrected for, if necessary.

Under conditions of zero sound reflection and if the standing waves are corrected for by proper manipulation of the microphone or reproducer or both, the envelope of the amplitude of the decaying sound waves should be a true logarithmic curve. In practice, it is attempted to so damp the room, that this condition will be approached. Every room will have a critical frequency at which the logarithmic decay will very nearly approach the theoretical. At the other frequencies, this condition will vary. Also, the decrement of the room will vary with the frequency of the sound. It is possible, however, to reduce these values to practically negligible amounts for all frequencies.

The oscillograms of the sound decay of the room in the Material Laboratory are shown for 250 cycles, 500 cycles, and 1000 cycles (Figures 6, 7 and 8). The decrement at all three frequencies is nearly alike and the time period is so short as to be satisfactory for the purpose intended. These curves show a sound reflection damped room but not a 100 per cent sound proof room. Some of the irregularities in the curves, therefore, are due to extraneous sounds not inherent in the room. From an examination of the curves, it is apparent that 250 cycles is the nearest approach to the critical frequency of the room and indicates a condition very nearly approaching the ideal. Some irregularities in these curves are also caused by standing waves for which no special compensation was made while taking these curves, as the microphone was stationary

for all three sets of data, and the same spacing of microphone and reproducer was used for all three cases, purposely to note the effect of testing at various frequencies with the same set-up.

As an illustration of the efficacy of the sound damping treatment of compartments, five curves at 250, 500 and 1000 cycles are shown for an untreated room with a high sound reflection (echo) condition (Figures 9, 10, 11, 12 and 13). This room has the same dimensions 20 × 20 × 13 as the compensated sound testing room. The effects of reflection, standing waves and external noise are very irregular and the time decrement is very appreciable. It can be seen at once that a room of this character would not lend itself to sound testing.

In testing the reproducer, standing wave effect is encountered. There is no known method of eliminating this phenomena as an inherent characteristic where any walls exist. The microphone can be removed to a different and selected location for each frequency when testing, but this course is not desirable. To overcome this effect, the microphone is set on a specially designed rotating arm passing the microphone through all vertical planes in line with the reproducing beam and moving it through a six-foot circle in the horizontal plane. The microphone is rotated about ten times per minute and the readings of sound pressure are made at the maximum of any rotation. Actually, the meter needle will oscillate through several divisions at regular intervals corresponding to the turn of the rotating microphone. The maximum value of this oscillation is read.

Two speaker curves (Figures 14 and 15) are shown, both on the same speaker at the same load. In Figure 14 the microphone was set at twelve feet from the reproducer, and all readings taken at that point. At 4000 cycles, there was no registered response, although the speaker was emitting this frequency at a considerable volume. This was due to the fact that the microphone was placed at a node in the standing sound wave, and while sound was present, there was no variation of pressure at the microphone diaphragm. The ear placed at the point where the microphone failed to register also recorded very markedly decreased volume of sound. This effect is compensated for by rotating the microphone

on the specially constructed arm, and all testing is done with the rotating microphone. The second curve on the speaker (Figure 15) shows the effect of rotating the microphone in smoothing out the response and compensating for the effect of standing waves in the room. By comparing these two curves, the different character of the results is clearly noticeable.

The equipment above described comprises the sound testing apparatus in the Material Laboratory used for testing and standardizing sound producing and reproducing equipment for the Navy, including microphones, loudspeakers and sound motion picture equipment.

Illumination Equipment. Design of fixtures and general lighting systems for plotting rooms of battleships and cruisers have been investigated and the results put to practical use afloat.

Navigation Lights. In collaboration with one of the largest glass manufacturers in the United States, tests have been conducted to determine the best material and colors for navigation and signal lights for the Navy which up to the time of this investigation were not satisfactory. The following characteristics for glass for these uses are imperative:

(a) The glass must be weather resisting (this being especially the case with submarine running and signal lights).

(b) The glass must be highly transparent to permit the greatest visibility of a small light source.

(c) The transmission or transparent qualities must not lessen during service use.

Extensive tests were conducted to determine the proper physical and chemical properties and rigid specifications were drawn up to secure the most satisfactory glass for this purpose. During the course of this investigation, it was determined that a zinc boro silicate glass with color imparted by silenium gave the best results for red glass, although boro silicate glass was found to be unsatisfactory for clear glass or green glass where it was found necessary to use a high density lead glass.

As a result of this investigation, red, green and clear lights were developed and standardized, which, using the same source of illumination, enabled these lights to be seen much farther; and a green light was developed of such a tint that it eliminates the

chance of confusing green lights and clear lights with a yellowish tinge, which had been one of the great difficulties with navigation lights before this investigation.

Protective Industrial Lenses. An investigation involving optical qualities and mechanical strength to develop protective lenses for arc welding and other work involving intense illumination. During this investigation, it was found that many of the colored lenses in use by arc welders gave a false sense of security, in that they permitted an excessive amount (up to as high as 30 per cent) of the dangerous infra-red rays to pass to the eye, which would result in serious eye trouble and possible blindness, if the eye was exposed to these rays for a sufficient length of time. Furthermore, it was determined that a great many of these colored welding glasses were neither of optical glass nor parallel-faced, but instead were made of non-parallel-faced window glass, resulting in eye strain, in addition to the eye injury from the infra-red rays. As a result of this investigation, all colored welding glasses accepted by the Navy must be parallel-faced optical glass and, tested by a radiometer, must not permit the transmission of a greater amount of infra-red rays than .5 of 1 per cent.

At this time a parallel investigation was conducted on safety lenses for chippers and caulkers, a great many of which were found to be of the same poor type of non-parallel-faced window glass as was found in the colored protective lenses, resulting in severe eye strain, causing the chippers and caulkers to neglect the use of the goggles, thereby subjecting themselves to the very eye injuries which the use of the goggles were supposed to prevent. Furthermore, the glass was easily shattered by impact of flying fragments with the grave danger of pieces of the glass penetrating the user's eye, causing serious injury or destruction of his eyesight. In these protective lenses parallel-faced optical glass was insisted upon and a drop-ball test was developed and used, which brought into use hardened glass, which would resist the impact of flying fragments. (The lenses must withstand a 39-inch drop of a 5/8 inch steel ball weighing .565 ounces.) This investigation and the high standards insisted upon by the Laboratory met with considerable opposition by certain manufacturers on the ground that the Navy was demanding an excessively high

standard and a product which was impossible to manufacture, but as a result of these high standards set, not only has the Navy secured lenses which are a real protection to the eye of the users, and at less cost for the present standard high grade material than for poor grade material previously purchased, but the Navy standards for protective goggles have been embodied in the Federal Safety Code and generally adopted by the commercial interests throughout the United States.

Aviators' Goggles. A similar investigation and tests were conducted in connection with the design of aviators' goggles. This investigation involved repeated flying by a laboratory engineer under service conditions, resulting in the design of the Navy Pilot type of goggle which embody the use of interchangeable hardened spherical lenses corrected to neutrality. Patents covering features of design were granted to one of the Laboratory personnel who assigned manufacturing rights to the Navy Department.

Searchlights. Tests of the original Beck high power arc and subsequent development work in conjunction with the manufacturer resulted in the production of the present high power arc searchlight. In connection with this work, greatly superior high power arc lamp carbons were developed, and an investigation was made of the characteristics of searchlight mirrors and searchlight beams.

Non-Scatterable Glass. Investigation of and preparation of specifications for the use of "Non-Scatterable" glass aboard ship.

Nitrogen-filled Optical Instruments. An investigation was conducted and specifications were drawn up covering the use of Nitrogen in Optical Instruments to prevent fogging of lenses and corrosion of metallic parts, due to condensation of moisture within the instruments; with special reference to submarine periscopes.

THE BATTERY SECTION.

This section conducts exhaustive tests of portable storage batteries submitted by manufacturers for initial approval and of portable batteries selected to represent each individual Navy contract; tests of the large type storage cells used as power supply for propelling motors of submarines when running submerged;

and acceptance tests on all types of dry cells used in the Navy. In addition, this section also tests and inspects all portable electric tools.

It is equipped with all the necessary equipment, such as low voltage charging generators, exciters, salt water and carbon pile rheostats, and test circuits; with a conditioning room maintained at a constant temperature of 70 degrees F. by means of water cooling coils and automatically controlled electric heating coils, for testing dry cells, and with small prony brakes and a dynamometer for testing portable electric tools.

This section is operated on a 24-hour schedule (three 8-hour shifts) so that the portable storage batteries and submarine storage cells may be charged and discharged without interruption.

Tests are continued until breakdown or until the end of useful life. From test results obtained, the probable life and operating characteristics when in service are estimated. Incidentally, these exhaustive life tests are seldom undertaken in the commercial field because of the time and cost involved.

In connection with battery tests, tests have been conducted on separators of new design, new types of grids, sealing compound, etc., all of which have proved to be of value both to the Navy and to the manufacturers.

Storage Batteries. Portable storage batteries of 16, 50, 100, 200 and 300 ampere-hour sizes, are tested for capacity, life and general operating characteristics. The capacity is determined at various states of the life by discharge, to the end voltage, at the 10-hour rate. The life is determined by discharging (after suitable charge) for exactly two hours, or less, if the limiting voltage is reached. These cycles are continued until the batteries have fallen below 80 per cent of their rated capacity. The minimum life required is from 350 to 450 cycles, depending on the size. Each of the various sizes of portable batteries are grouped on a separate circuit controlled for charge and discharge rates by carbon disc rheostats on 17 hand-operated battery control switchboards.

The submarine cells, which average about 4500 ampere-hours at the ten-hour rate, are tested similarly to the portable batteries,

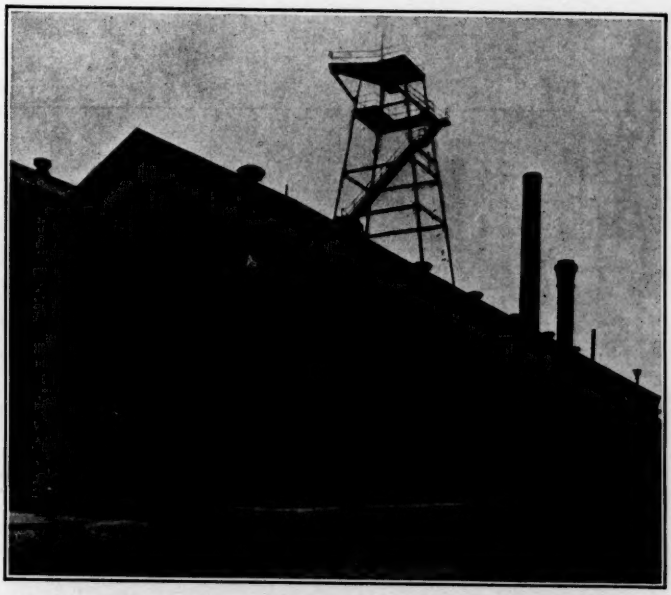

FIG. 1.—THE MATERIAL LABORATORY, U. S. NAVY YARD, NEW YORK.

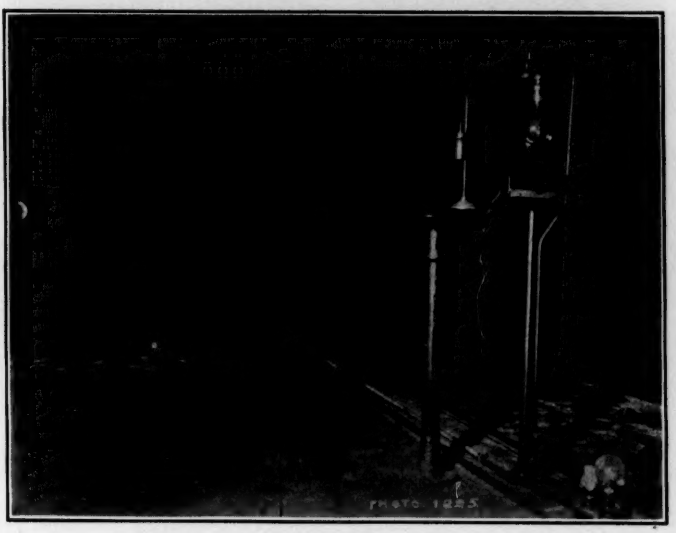

FIG. 2.—80-FOOT BENCH PHOTOMETER.

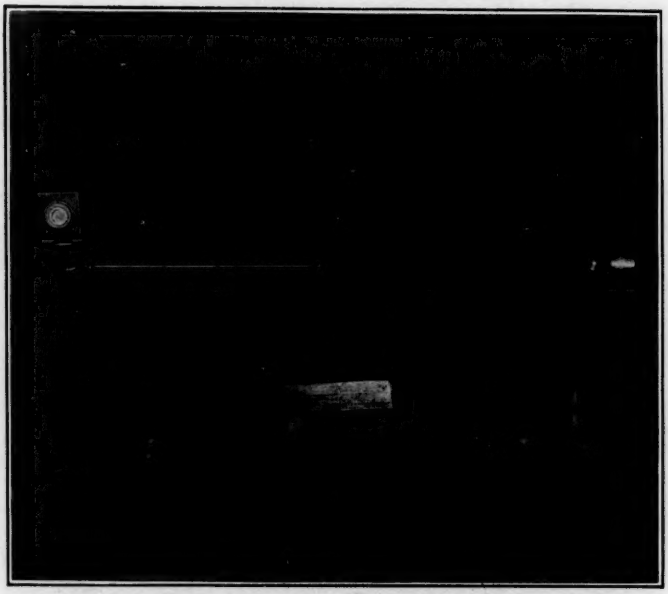

FIG. 3.—COMPENSATED SOUND TESTING ROOM.

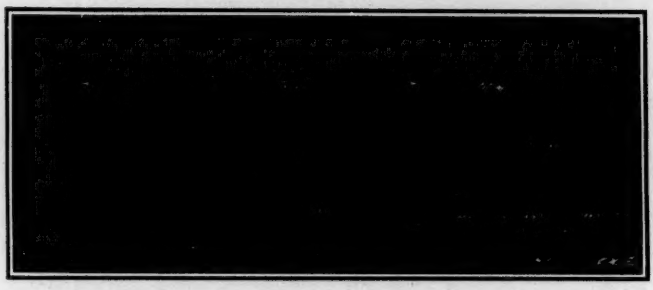

FIG. 6.

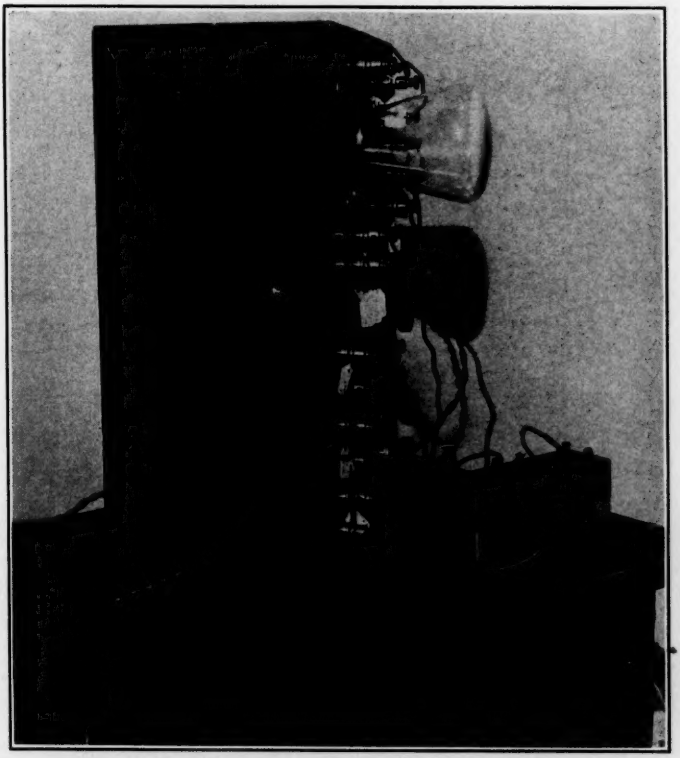

FIG. 4.—CATHODE RAY OSCILLOGRAPH TUBE.

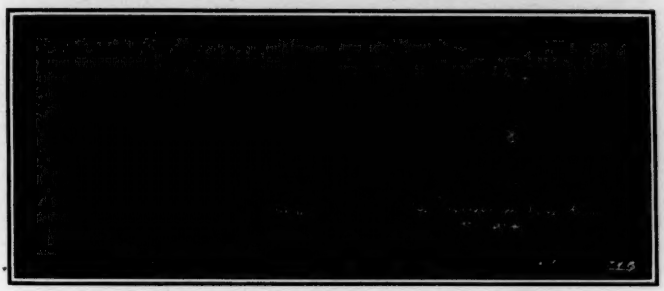

FIG. 7.

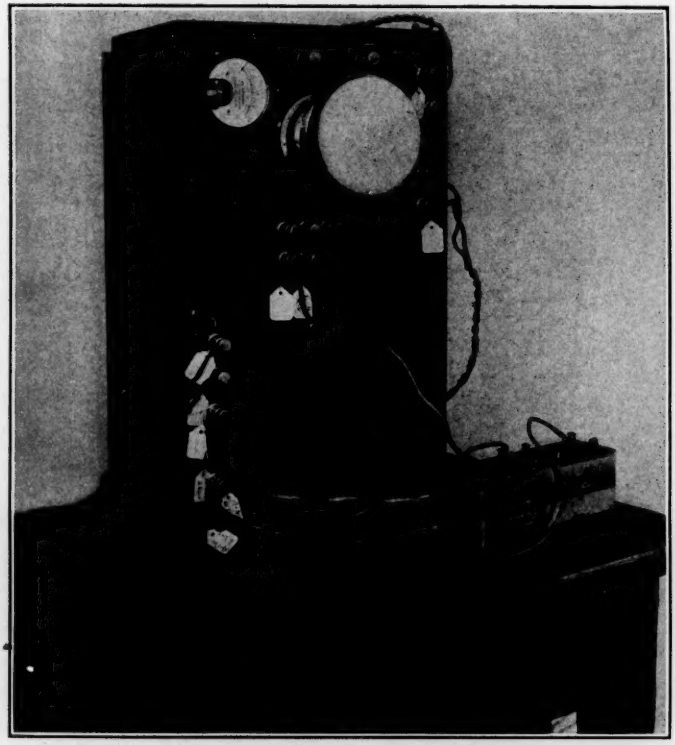

FIG. 5.—CATHODE RAY OSCILLOGRAPH TUBE.

FIG. 8.

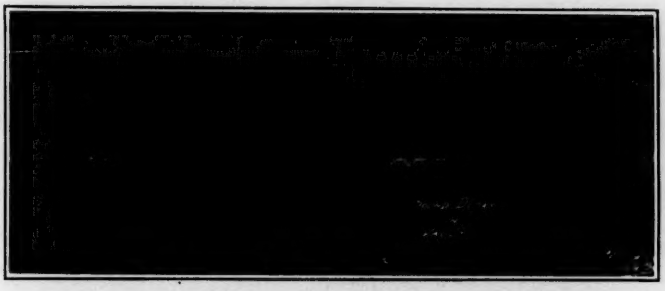

FIG. 9.

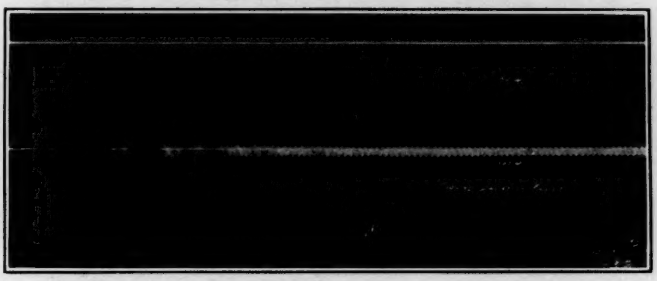

FIG. 10.

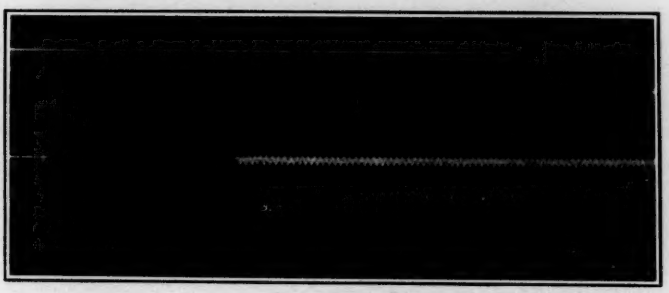

FIG. 11.

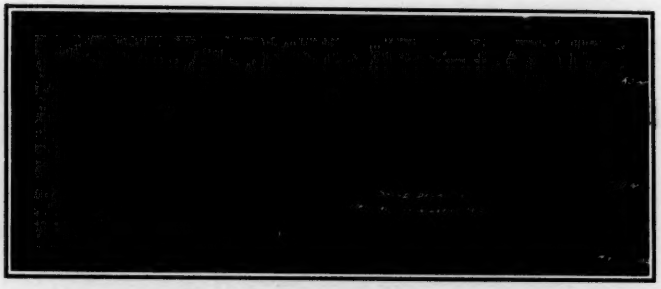

FIG. 12.

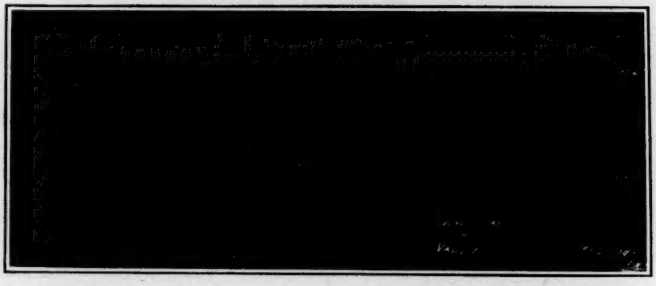

FIG. 13.

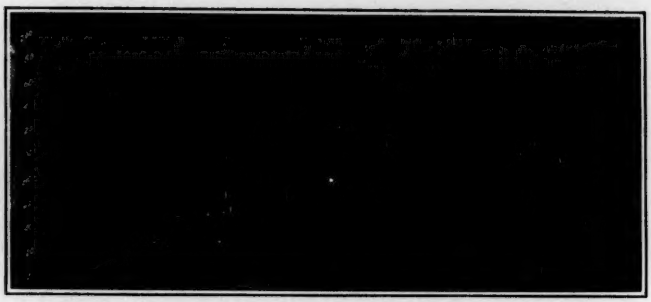

FIG. 14.

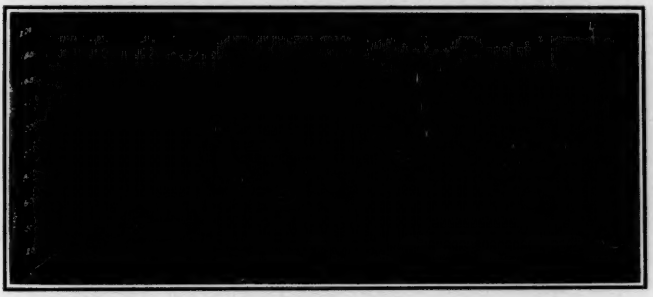

FIG. 15.

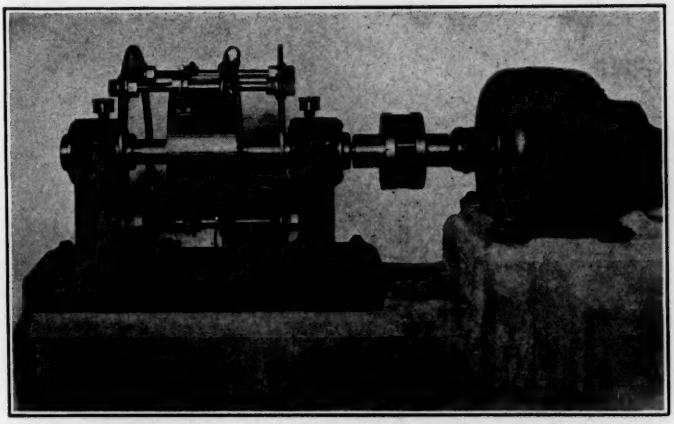

FIG. 16.—CARBON BRUSH TESTING COMMUTATOR.

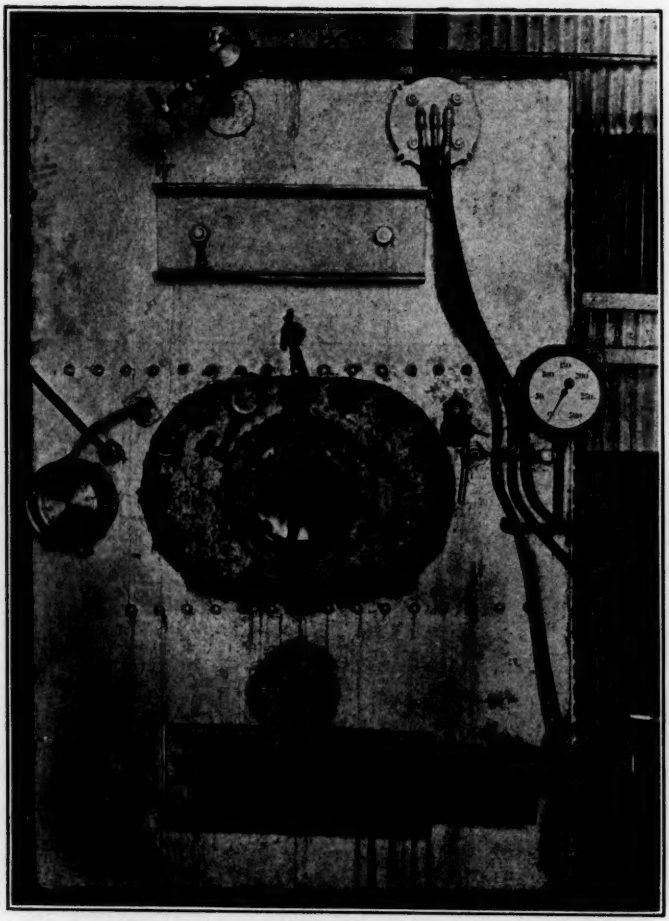

FIG. 17.—UNDER-WATER CUTTING TORCH, OUTSIDE OF TANK.

FIG. 19.—UNDER-WATER CUTTING TORCH, SPIRALS CUT UNDER SUBMERGED CONDITIONS.

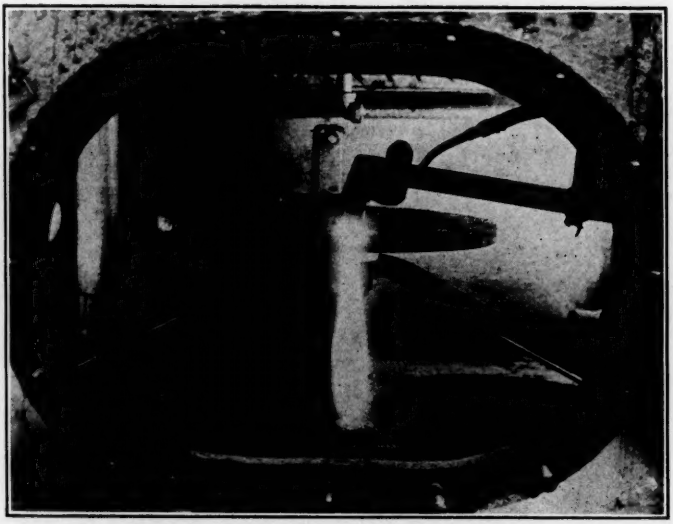

FIG. 18.—UNDER-WATER CUTTING TORCH, TORCH IN OPERATION, TANK OPEN.

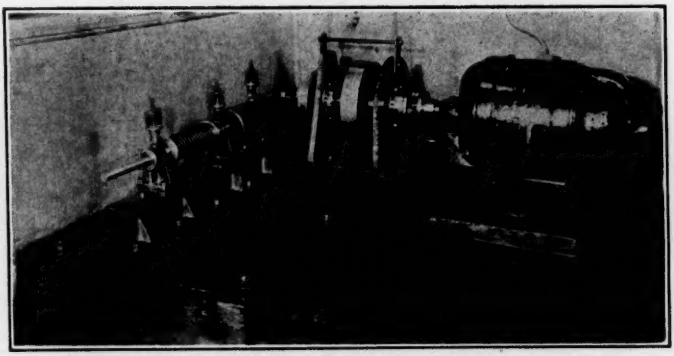

FIG. 20.—DIESEL ENGINE VALVE SPRING TESTING MACHINE.

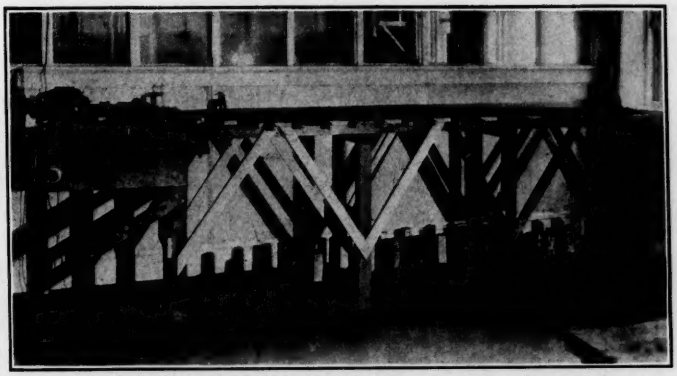

FIG. 21.—ABRASIVE PAPER TESTING MACHINE.

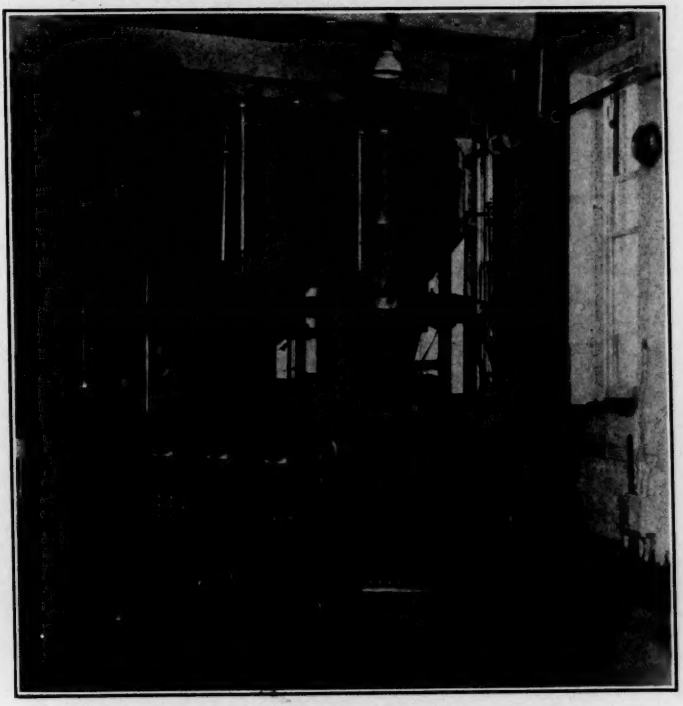

FIG. 22.—SCORSBY TEST STANDS AND CONTROLS.

except that the characteristics at a series of discharge rates are included in the life test.

The best results so far obtained on life tests of submarine cells was with the Iron Clad batteries that withstood 1600 cycles over a period of continuous charge and discharge of over 30 months. Assuming 50 cycles per year for a submarine in active service, such a battery would have a useful life of 8 years of active service afloat.

Included in the Portable Storage Battery Room Generating Equipment are:

(a) Two 30 Kw. 15 volt charging motor generators.

(b) 2 Kw. exciter motor generator.

(c) Control panel and discharge water-cooled tubular rheostat.

(d) 22 1/2 Kw. 75 volt motor generator (used for supplying, in parallel, the 17 battery control switchboards for portable storage batteries).

For general laboratory service, where a constant voltage is required or for standby service, a group of glass jar 300 ampere-hour batteries is maintained in a separate room.

Dry Cells. For these tests a conditioning room with automatic constant temperature control was built as, in testing dry cells, it is essential that a constant temperature be maintained for the reason that dry cell voltages are materially affected by relatively small changes in temperature.

The dry cells (flashlight batteries, ignition cells, and radio "B" batteries) are discharged through fixed resistances of specified amounts to an end point where the cells are considered to have reached the minimum useful voltage. Three types of tests are used in this work:

Continuous discharge within one month of manufacture. Intermittent discharge for a short period daily. Continuous discharge test after standing as received on the shelf, for six months.

The number of hours performance under the various tests is computed into performance units evaluated one for continuous discharge, four for intermittent discharge, and eight for shelf life. Purchases are made based on the lowest price per guaranteed performance unit.

By selecting samples for tests at random from each order, a constant check on the material being purchased is maintained.

The value of the contracts for portable storage batteries and dry cells represented by the tests being conducted in this section at the present time amounts to $420,000.00.

Portable Electric Tools. Tests of portable electric tools are for the purpose of revision of specifications and the approval of satisfactory types for naval service. The tools are connected to the dynamometer or prony brake and accurate performance data are obtained. Many very important results have been obtained, such as proper cutting speeds for drills, use of proper bearings, elimination of excessive noise, and proper balancing of armatures, leading to the procurement of better equipment for the Navy.

THE POWER SECTION.

This section is devoted to testing power driven equipment and accessories including control devices.

A wide range of test equipment is required to cover the many forms of power machinery in use in the Naval Service. For the heavy machinery, a 12 foot × 20 foot test plate has been installed. This plate is rigidly constructed of steel beams and concrete, supported by piles and cross-beams well below tide water.

Steam pressure is obtained from the Yard power house, to operate steam driven turbines, reciprocating engines or pumps, up to 300 horsepower.

Service lines and auxiliaries are installed, such as fresh and salt water, compressed air, a 150 horsepower surface condenser, a 50 horsepower electrical dynamometer, various sizes of generators and an electric power board with load rheostats of 300 Kw. capacity.

Auxiliary and test electric power is provided as follows:

A 100-100 Kw., 125-250 volt, double end motor generator.

A 50-20 Kw., 125-250 volt, double end motor generator.

A 25 Kw., 125 volt, motor generator.

A 2000 ampere, 15 volt motor generator.

An extensive system of control is used with the above sets, together with a large number of instruments, rheostats and switch-

ing devices, so that motors or generators of all ranges of voltage frequency or sizes used in the Navy, excluding the main drive, can be tested for full specified requirements.

Shock Proof Circuit Breakers. The extensive application of electrical power for the main drive for ships of the U. S. Navy has introduced some problems which do not exist to any appreciable extent in the commercial field. Some equipment must be "shock proof" to the extent that it is not affected by the shock of gunfire. The development of shock test equipment was begun in the Material Laboratory about 1917 and the present form of the shock test stand used was adopted as standard. Shock tests were first applied to circuit breakers and later extended to control and operating equipment.

Arc Welding Sets. The increasing importance of electric arc welding has made it desirable to develop test methods for accurate determination of the characteristics of electric arc welding sets. The oscillograph has played an important part in the development of these tests. A special air core current transformer has been designed and built for use in measuring the effective reactance in a welding circuit while carrying direct current.

As a result of complete laboratory tests on all commercial makes of welding sets, comparative Work Factors were obtained and rigid specifications were prepared, which are now in use, which reduce the acceptance of contract deliveries to a scientific basis and practically eliminates the personal element.

Carbon Brushes. The development of test methods for brushes for electrical machinery was undertaken in 1924. A survey of the commercial field indicated that no standard test methods existed. Types of testing equipment used by some of the commercial concerns for making operating tests were tried and found unsatisfactory. It was also found that the commercial concerns placed very little reliance on the results obtained.

The general practice of manufacturers and users of carbon brushes was to rely almost wholly on service tests to determine the suitability of a given grade of brush for a certain class of service. The conditions of such service tests are not subject to control. The commutators of commercial machines vary considerably

in roughness and eccentricity. It has been found that an eccentricity of only .0005 inch in a 10 inch diameter commutator, affects materially the determinations of contact drop and coefficient of friction at usual commutator speeds.

Testing new grades of brushes on machines in service is not good practice either from an engineering or from an economical point of view. The test may result in excessive wear or damage to an expensive machine and the results obtained are inconclusive.

Lack of standardized laboratory tests and the dependence placed upon operating tests under undefined service conditions probably account for the great variety of grades on the market and the frequency of withdrawal of old grades and the appearance of new grades.

Therefore, in order to progressively develop carbon brushes, it is highly desirable that operating characteristics be determined from laboratory tests, as such tests form the only logical basis for comparing brushes of different manufacture.

The importance of selecting proper brushes for replacements on motors and generators cannot be over-estimated. While a new set of brushes may cost only a few dollars, a set having the wrong characteristics may within a short time, place a motor or a generator costing several thousand dollars in the repair shop and result in the expenditure for repairs of many times the cost of the brushes.

When a new motor or generator is purchased from the manufacturer under naval inspection and test, it is reasonable to assume that the brushes supplied by the manufacturer will be satisfactory under all normal conditions of operation on board ship. Therefore, if the brushes purchased for replacement are of the same grade as originally furnished, no new difficulties with the commutation of the machine will be experienced after the installation of the new brushes. Experience has shown that the only way to insure that the new brushes are of the same grade as originally furnished, is to purchase all brushes, for replacements, from the manufacturer of the motor or generator.

When brushes are not purchased direct from the manufacturer, it is necessary to make an open purchase of brushes or brush material under specifications.

After considerable research, it was found that the unsatisfactory test data obtained was due to varying air pressure under the brush, when in operation, and an incorrect theory as to contact resistance. Testing equipment was designed to eliminate the varying air pressure under the brushes. Ratings based upon a correct theory of contact resistance was adopted. Test data obtained on the specially designed motor driven artificial commutator (Figure 16) have been found to be consistent and to satisfactorily indicate true operating characteristics. The test cylinders are ground so as to have an eccentricity not greater than .0002 inch and can be operated at any speed up to 7000 feet per minute.

Standard laboratory test methods were evolved and specifications for purchase were prepared covering the physical characteristics of brush material, such as hardness, specific resistance, transverse strength, coefficient of friction, contact drop, maximum peripheral speed, current carrying capacity, percentage of ash and kind of impurities. From the result of several years of laboratory work, the many grades of commercial brush material were reduced to five Navy grades suitable for all classes of motors and generators in use in the Navy.

The test methods and detailed requirements are now covered by specifications.

Recently, after a long period of educational work with the manufacturers and users of electrical machinery, the Navy has adopted the policy of operating only under-cut commutators in lieu of the flush mica commutators. The adoption of this policy will eventually result in reducing the number of standard Navy grades for brush material from five to three. The important phase of this work yet remaining is to accomplish the standardization of brush dimensions. The laboratory tests have clearly demonstrated that two small brushes are more than equal, electrically, to one large brush of equal area. The natural assumption from this is that a brush of moderate size suitable for a one horsepower motor is entirely suitable, in multiple units, for motors up to 500 H.P. or generators up to 300 Kw. The economic advantages of one size of brush and not more than three grades of material, for all purposes, can not be overestimated.

Ventilating Sets. In connection with this investigation, a plenum chamber and the necessary auxiliary equipment has been constructed during the past year for testing propeller type ventilating fans.

A centrifugal fan is used for varying the static head on the plenum chamber. The fan for test is mounted in a suitable opening at the far side of the chamber. The recent application of airplane propeller design to ventilation problems and the appearance of several new types of fans for ship use necessitates careful determination of the static head, velocity, volume, efficiency and noise characteristics at various loads.

STANDARD INSTRUMENT SECTION.

In about 1914 a section devoted entirely to electrical instruments and meters was established. Prior to that time, all instruments, including the standards, were accessible to all members of the Laboratory for general use without any supervision as to accuracy or condition. The electrical standards are now housed under plate glass covers mounted on slate piers and carefully maintained at 1/10 of 1 per cent accuracy by checking against standard voltage cells, shunts and potentiometers, which have been certified by the Bureau of Standards in Washington, D. C.

The standards are used to check the working standards of the other sections of the Laboratory and the large stock of reserve instruments held in this section. These reserve instruments include an almost complete range of A. C. and D. C. voltmeters, ammeters, watt and watthour meters, frequency, power factor and capacity meters, current and voltage transformers, thermal ammeters and voltmeters, condensers, megohm and dial resistances, meggers, A. C. and D. C. wheatstone bridges, phase shifters and galvanometers. These instruments and standards are maintained at a high degree of accuracy and are used in all parts of the Laboratory as needed for special tests.

Bureau suitability tests on the above line of instruments and meters are conducted in this section.

Insulating Materials. The increasing importance of molded insulation is illustrated by the fact that this subject has been

developed from a 2 page leaflet in 1914 to a 26 page specification for molded forms and a 12 page specification for switchboard material in 1930. This section has handled this subject since 1914 and has the necessary equipment to conduct all tests, except radio frequency tests. The equipment consists of apparatus to test dielectric strength, surface and volume resistance, impact, transverse, tensile and compression strength, moisture absorption, inflammability and heat distortion. The laboratory has cooperated with the American Society for Testing Materials to standardize the methods of testing insulation and uses the A. S. T. M. methods as far as they have been standardized and adopted by the Society.

Salinity Indicators. Investigation and tests have been conducted, in the last few years, in cooperation with the manufacturers to develop a satisfactory electrical system of indicating salinity or impurity of boiler feed water. The work involved the development and testing of rugged and dependable instruments and suitable salinity cells.

Rugged cells have now been developed and approved. In one type the cell electrodes automatically correct for temperature changes of the water under test, through bimetallic construction of the electrodes. This type is being installed on board ship and considerable success is anticipated as the instruments are merely A. C. milliammeters in series with cells and operate from a constant voltage transformer. This section checks these systems after installation and in operation and advises what changes are necessary in order to secure maximum efficiency in service.

Electric Logs. A test is being conducted on a Swedish Log of the Pitot tube type. The bellows of the log apparatus operates an electrical device and indicator which consist of a D. C. milliammeter and ampere-hour meter in series. The milliammeter is graduated in knots, and indicates the speed of the ship. The ampere hour meter adds up the knots and by timing the disc, the accuracy of the knots indicated can be checked. A calibrated adjustment can be used if the knots logged do not check with the calculated knots. An accuracy within about 2 per cent at the normal operating speeds can be expected from this device. It is believed that this is the first laboratory test conducted on an apparatus of this

type and should eliminate many defects before installation is made on ship board.

In addition to the types of instruments noted above, tests are conducted on such devices or materials as tachometers, sounding tubes, resistance material, weatherproof sockets, air and radiant heaters, desk fans, etc. These devices and materials are being constantly improved through these laboratory tests conducted in cooperation with the manufacturers.

MISCELLANEOUS ELECTRICAL SECTION.

This section is fitted with power circuits, high voltage equipment permitting breakdown determinations up to 150,000 volts A. C. and test instruments for conducting Bureau approval tests and research work on miscellaneous A. C. and D. C. electrical equipment, requiring low current consumption, and insulating materials (including varnishes and lacquers).

Insulated Wire and Cable. Investigations have been made, test data obtained and navy specifications revised on all types of electric cables, substituting reinforced rubber sheathing for lead sheathing for mechanical and moisture protection, substituting varnished cambric insulation in place of rubber insulation, reducing overall diameters and weights of cables, and determining suitable protective coverings on ignition cables against ozone effect on rubber insulation.

Engine Telegraph Systems. Apparatus has been developed for testing all types of mechanical and electrical telegraph equipment and a large amount of work has been carried on in determining the operating characteristics of such equipment and the synchronous motors used in connection therewith.

Revolution Indicators. Equipment has been installed and tests have been conducted on many types of shaft revolution indicators and systems, both mechanical and electrical, to determine suitability for Naval use. These tests cover general operating characteristics, calibration measurements and the effect of external vibration, shock, heat and stray magnetic fields on the accuracy of the indicators and systems.

Electric Refrigerators. Equipment has been installed for determining the operating characteristics of various types of portable electric refrigerators. In order to determine the operation of such equipment under rough sea conditions, to which it would be subjected when installed on board ship, each refrigerator is subjected to rolling, pitching and yawing of 40 degrees, 20 degrees and 10 degrees on each side respectively. Tests, relative to food compartment temperatures, power consumption, thermostating periods, ice freezing, box leakage and general operating features under ambient temperatures of 80 degrees and 100 degrees F. have been made to date on six different types of refrigerators.

Insulating Varnishes. Extensive tests have been made and data obtained on the physical, chemical and electrical characteristics of clear and black air drying and baking insulating varnishes.

The use of a suitable insulating varnish in the Navy is of prime importance for the reason that all motor and generator armature and field windings depend almost entirely on cotton, silk, linen or paper fabrics for insulation. These materials readily deteriorate and are highly hygroscopic, especially when not in operation. They are also highly absorbent of oil which leaks out or is thrown from the bearings. In order to keep the electrical machinery free from grounds and short circuits for a long period of time, a grade of insulating varnish which is highly resistant to moisture, oil, acids and alkalis is essential. The varnish should also dry in a reasonable time, and should remain flexible under all operating temperatures for long periods. Commercial grades of varnish, as a rule, are made for a low price market. Tests have shown them to be deficient in one or more of the qualities required for Naval use. The use of an inferior varnish which deteriorates rapidly from heat, is soluble in oil, or permits the entrance of moisture into the interstices of the insulating fabrics, usually results in numerous and frequent applications in order to avoid breakdowns. The excessive use of varnish is harmful because it closes the cooling air spaces, retards natural heat radiation from the windings and in some instances causes unbalance and interferes with the rotation of the armature.

The following Laboratory apparatus is used for testing the resistance of insulating varnish to various liquids. Brass rods are dipped in the varnish and are dried in a special heat cabinet under standard condition. The rods are then immersed as electrodes in glass beakers containing the test liquid. By means of a second bare electrode and an electric circuit of 110 volts, a voltage strain is placed on the varnish film. Any breakdown of the film will immediately indicate on a pilot light in series with the circuit. To determine the effects of heat and oil on the varnish film, thin, flexible copper strips are dipped in the varnish and suspended in a drying oven. Examination is made from time to time to determine the number of hours of useful life of the varnish film.

As a result of these tests, a highly satisfactory black air drying and finishing insulating varnish meeting all naval requirements has been developed and specifications have been issued.

High Voltage Resistance Materials. A high voltage testing set is used for applying the dielectric test on various insulating materials having a dielectric strength greater than 1000 volts, such as moulded form, switchboard panels, mica sheets, varnish films, varnished cambric, and insulated cables. The set consists of:

(a) A 15 Kw. motor generator equipped with both an A. C. motor and an optional D. C. motor which drive a 3 phase alternator.

(b) A 20 Kva. 150,000 volt transformer and 10 Kva. 20,000 volt transformer both of which are connected to a marble connection panel. The test specimens are placed on the horizontal marble table where the high voltage is applied after the proper combination or range of operation is obtained by switch combinations. Calibrated spark balls are used to protect the test circuit from excessive voltage, while the applied voltage is determined by means of accurate voltmeters on the primary control panel which read in terms of the ratio of primary to secondary transformed voltage.

High voltage dielectric testing has played a very important part in the development of electrical apparatus. Electrical insulation, without which no electrical installations would be practicable, fails usually at its weakest point. The weak point may be due either to a material fault or to a design fault.

Low voltage tests expose only the most glaring faults.

High voltage tests furnish knowledge of defects which would otherwise develop after the material had been in service for some time, furnish information of the comparative value of competitive materials and indicate the factor of safety of the weakest spot. High voltage tests are also used extensively on assembled electrical machinery both before and after installation.

For portable use, a compact, adjustable 5 Kva. transformer outfit, with a maximum range of 3000 volts, is used for both laboratory and field work.

This section also conducts tests on miscellaneous materials and appliances such as insulating tape, mica, varnished cambric, insulating compounds, bells, buzzers, relays, sockets, switches, etc.

The variety of materials and appliances covered necessitates constant modification of test equipment to suit conditions.

The test data obtained in close cooperation with the manufacturers have proved of value in obtaining materials and appliances of high standard for Naval use.

Work towards strandardization of test equipment and test methods has been carried on in conjunction with the American Society for Testing Materials.

THE MECHANICAL SECTION.

This section investigates and tests the following:

(Items marked * are later described more in detail).

*Underwater cutting torches.
*Aluminum alloys.
*Fire extinguishers, foam and carbon dioxide.
*Oxy-acetylene torches.
*Oxy-hydrogen torches.
*Hacksaw blades.
*Rescue breathing apparatus.
*Fastness of dyed fabrics.
*Fabrics, strength of.
*Materials for Ship Salt Water Mains.
*Bearing Metals.
*Valve springs, Diesel engines.

*Corrosion resisting metals and coatings.
*Metallographic determinations.
*Physical properties of metals.
*Aging of rubber and rubber compounds.
Airplane plywood (laminated veneers) water resistant.
Piston rings (cast iron).
Pyrometers.
Thermometers.
Relief valves; oil, air and steam.
Lubricating greases.
Gauges, pressure and vacuum.
Leather belting.
Marine glue.
Gaskets, oil and gasoline.
Diving equipment.
Etc.

Under-water Cutting Torches. One outstanding instance of such investigation and development has been the perfection of the Underwater Cutting Torch. During the Great War the Bureau of Construction and Repair realized the need for some efficient means of salvage work in dismantling steel on under-water wreckage and directed an investigation with a view to developing the oxy-acetylene torch for under-water cutting. It was also necessary, if such an adaptation could be made, to determine the working conditions with respect to gas and air pressures best suited for various depths of operation.

A steel tank about 6 feet wide, 7 feet high and 5 feet deep was fitted with a standpipe 100 feet high. Various hydrostatic pressure depths could be obtained by filling the tank and stand pipe to any height up to 100 feet. The stand pipe also acted as a vent for any gases and thus prevented the collection of gases with consequent increase in pressure.

One side of the tank was fitted with a glass port through which the interior could be observed. A horizontal circular steel table was installed in the tank on a level with the port and connected through suitable gears and stuffing boxes to a crank handle on the

outside of the tank by means of which the table could be revolved by hand.

An oxy-acetylene torch developed at the Navy Yard, Puget Sound, was tested at the Laboratory in the summer of 1922. These tests were unsatisfactory, because it was found that the tips burned out and that the flame frequently became extinguished when used under water. As no satisfactory progress could be made, the experiments were discontinued after every effort had been made to make the torch function satisfactorily.

Considerable valuable information was obtained, however, especially in the development of the testing tank.

Because of the difficulty experienced in maintaining a flame under water continuously, when using acetylene gas, regardless of many makes of tips and torches tried, it was determined to experiment with hydrogen gas.

A regulation oxy-hydrogen cutting torch was fitted with an air jacket adapter enclosing the torch tip. The air jacket when connected to an air supply created a conical air shield around the oxy-hydrogen tip which, when submerged, permitted the combustion of the oxy-hydrogen gases.

The cutting torch thus equipped was held in a holder in the tank by means of which and by a system of outside mechanical controls, the torch could be operated under water by an operator outside the tank.

An electric igniter was installed in the tank which could be rotated from the outside, so as to place the spark.

Very gratifying results were obtained. It was found that practically any thickness of mild steel plate could be cut at any depth up to 103–1/2 feet of water, the limit of pressure of the test tank. Furthermore, the flame burned continuously, it being impossible to extinguish it even by violently shaking the torch under water. The only way by which the flame could be extinguished was by turning off the gases. While the heat value of hydrogen is lower than that of acetylene, the longer flame inherent with hydrogen was an added advantage in under water cutting.

The work cut by the torch consisted of a circular steel plate secured to the revolving table. As the table was revolved, the

torch operated from outside was made to cut spirals from the plate from the outer edge to the edge of the table.

The operator with the above outfit, all of which was designed by the Laboratory personnel, could cut various thickness of steel plate at various hydrostatic depths and observe at all times the behavior of the torch.

Experiments extending over many months were conducted to determine the proper working pressures of compressed air, oxygen gas and hydrogen gas for cutting mild steel plate up to 1–1/2 inches in thickness at depth intervals up to 103–1/2 feet of water. These data were tabulated and aided greatly in standardizing the operation of underwater cutting with oxy-hydrogen torches.

The following abbreviated table will be of interest:

Working gas pressures for operating underwater cutting torch.

Depth		Thickness of Work Inches	Gas Pressure		
Feet	Water Pres. lbs.		Air lbs.	Hyd. lbs.	Oxy. lbs.
103½	45	½	55	60	62
103½	45	1	55	60	70
103½	45	1½	55	60	90

The torch developed by the Laboratory was successfully used in salvaging the S-51 and the S-4. The Navy Department has applied for a patent in the name of the laboratory engineer who developed the torch, who has assigned to the Department the right to use the torch without reimbursement.

The construction of the test equipment is shown in the accompanying photographs:

Figure 17 shows the outside of the tank.

Figure 18 shows the torch in operation with the tank open.

Figure 19 shows spirals cut under submerged conditions.

Aluminum Alloys. Owing to the tonnage limitation of individual cruisers and aircraft carriers, established by the Washington Treaty limiting naval armaments, it has been necessary for the

Navy Department to make extensive use of aluminum alloys for such ship construction that does not require greater strength than can be obtained by the use of such alloys.

Due to the well-known susceptibility of aluminum and its alloys to corrosion when exposed to salt atmosphere, it has been found necessary to coat such alloys with protective paints. Extensive investigations were conducted by the Laboratory to determine the best paints for such purpose, a great number of such paints being applied to aluminum test panels and exposed to the weather as well as to a 20 per cent salt spray solution. The results obtained have been of interest and value. Further research and investigation is being conducted along these lines as well as in connection with special aluminum alloys.

Fire Extinguishers. Formerly 2–1/2 gallon portable foam and one quart carbon tetrachloride hand extinguishers were used on board ship and in motor boats for extinguishing gasoline and oil fires. The Laboratory conducted extensive tests on the efficiency of CO_2 extinguishers. These tests determined that portable CO_2 extinguishers have greatly superior fire extinguishing qualities over the mediums previously used in controlling oil and gasoline fires in compartments, tanks, or enclosed spaces, where the CO_2 gas can be directed and confined to the fire. Experience, however, has shown that, in a head wind, CO_2 gas is not equal to foam in extinguishing fire, due to the drifting of the gas from the fire, while foam is not displaced from the surface of the burning liquid by a head wind.

As a result of these tests, CO_2 extinguishers are being substituted for the portable foam and CCl_4 extinguishers for motor boat use, and extensive installations of larger units of the CO_2 extinguishers are being made on board ship.

OXY-ACETYLENE AND OXY-HYDROGEN CUTTING AND WELDING TORCHES.

For many years the Navy Department has been purchasing oxy-acetylene and oxy-hydrogen cutting and welding torches on a basis of apparatus furnished by contractors whose equipment has been found to be satisfactory for Naval use as a result of labora-

tory and service tests, but no attempts were made until recently to make a comparative evaluation of various makes of these torches, award having always been made in the past to the lowest bidder whose torch was on the acceptable list, no consideration being given to the superiority of torches offered by a higher bidder. Recently, the Laboratory has conducted an extensive investigation and tests to determine the relative efficiencies of the various torches on the market, said relative efficiencies being indicated by a Work Factor assigned to each torch.

For use in connection with these tests, a test board was constructed.

On this test board are mounted:

(a) Two flowmeters with pressure gauges for measuring the quantity of oxygen, hydrogen or acetylene gases used by various makes of oxy-acetylene and oxy-hydrogen torches and regulators.

One flowmeter is used for measuring high pressure gases (oxygen and hydrogen), the other for measuring acetylene.

Each flowmeter consists of a brass tube fitted with removable nozzle diaphragms at a joint in the tube, so that any size nozzle may be inserted as may be required by the rate of flow of gas under investigation.

(b) 6 foot glass mercury tubes to indicate the pressure at the outlet or low pressure side of the diaphragm when operating at low gas pressures.

(c) A 75 and a 200 pound pressure gauge for use when operating at pressures higher than can be registered by the mercury tube.

(d) 12 inch glass mercury tube for indicating high differential pressures.

(e) 6 foot glass water tube for indicating low differential pressures.

(f) 2-24 hour recording pressure gauges, to indicate the pressure variation of gas regulators when operating at different supply pressures.

All inlet and outlet hose connections are made at the bottom of the board to prevent fouling the instruments with hose.

The work factors determined are considered in connection with the price bid and award is made to the bidder with the highest quotient obtained by dividing the work factor of his apparatus by the price quoted.

By this method of awarding contracts for these torches, a notable advance in economy and efficiency has been achieved, where economy and efficiency can be considered as the product of work accomplished and price paid for the apparatus.

Hacksaw Blades. Investigations and tests are now being conducted to establish Work Factors for various makes of hacksaw blades.

Rescue Breathing Apparatus. A section is devoted to testing and repairing rescue breathing apparatus used by Naval personnel in entering compartments or spaces filled with smoke or other fumes which have made the air irrespirable (these masks and their use are entirely separate and distinct from poison gas masks).

In connection with this section, a school is maintained for the instruction of ships' personnel in the use and care of rescue breathing apparatus. Such personnel is instructed in the physiology of breathing, the effects of toxic gases and the detailed construction and use of the apparatus. Every man under instruction is required to wear the apparatus in a gas chamber filled with formaldehyde gas to familiarize himself with the use of the apparatus and the detection of gas leaks through or around the apparatus, so that he can gain perfect confidence and ease and ability to accomplish rescue operations in an irrespirable atmosphere.

Fastness of Dyed Fabrics. An investigation has been conducted in the selection of apparatus for testing the fastness of dyed fabrics.

Originally a quartz burner mercury vapor light was used for such tests. The two objections to the use of the quartz burner mercury vapor light are: (1) Too greatly accelerated fading; this light being many times as active as sunlight, and (2) Some colors are not affected by this light in the same way as by sunlight. As a consequence, it was found that while the mercury light greatly accelerated fading and indicated in a very short time the relative fastness of various dyes, it did not in all cases similate

the effects of exposure to the rays of the sun. As a consequence, a "Fadeometer" was purchased. The "Fadeometer" uses a carbon arc light and while its action is not as fast as the quartz burner mercury vapor light, it is found to be much more satisfactory in similating the action of the sun's rays. The "Fadeometer" has been found to be from two to twenty times as active as the sun's rays, depending upon the time of the year.

The Quartz Burner Mercury Vapor Light. A vertical quartz burner mercury lamp is enclosed in a cylindrical metal container. Portholes in the cylinder are located in a horizontal plane passing through the center of the burner. Each port is fitted with a wooden plug. Test specimens of colored fabrics are placed over the plugs and inserted in the ports. Exposure is continued for various periods, depending on the fastness of dye under test.

Comparison is made with results obtained on standard samples of dyed fabrics.

The "Fadeometer." A carbon arc light is enclosed within a metal cylinder provided with rectangular ports, over which the test specimens are secured and then covered with the duck apron shown. A water pan with large cotton wicks at the bottom of the instrument humidifies the air which is drawn to the top of the cylinder by the electric blower at the top. This humidified air passes over and through the test specimens keeping them cool and under normal atmospheric conditions.

Comparison is made with results obtained on standard samples of dyed fabrics.

Fabrics, strength of. Investigations are conducted to determine the strength and weight of fabrics, cordage, thread, paper, etc., and the drying time of paints, oils, and varnishes. As it was necessary to conduct these tests in a standard atmosphere unaffected by varying humidity and temperature, an air conditioned room was built with the necessary equipment to maintain automatically a constant humidity of 65 per cent $\pm$ 2 per cent and a constant temperature of 70 degrees F. $\pm$ 2 degrees. The equipment consists of a motor driven two-ton ammonia ice machine which cools a tank of Boudolot coils over which recirculated water trickles and is cooled to a temperature of 40 degrees to 50 degrees F. This

cooled water is sprayed across an air duct through which either fresh air or recirculated air is drawn by an electric blower. The air passing through the curtain of cooled water is brought to a humidity of 100 per cent, at 57 degrees F., under which conditions it has the same absolute humidity as that required for 65 per cent humidity and 70 degrees F. By means of thermostatically controlled steam heaters, the air temperature is raised to 70 degrees F., during which rise in temperature the relative humidity drops from 100 per cent to 65 per cent. These thermostatically controlled steam heaters also operate to keep the humidity and temperature of the room within the limits given above of the standard humidity and temperature of 65 per cent and 70 degrees F. respectively.

All test specimens are kept in the standard atmosphere for at least four hours before weighing or breaking. The drying time of paints and varnishes can be readily and accurately determined at various periods while the sample is continuously exposed to the standard atmosphere. A motor-driven Scott fabric tester is installed in the air conditioned room. It has a dual capacity of 100 pounds and 400 pounds. It is fitted with special clamps for holding various materials and with swivel heads so that the clamps are maintained in accurate alignment while the test pieces are being inserted and pulled. It is provided with an autographic recording mechanism which gives a continuous graphic record of the relation between strain and stretch.

Materials for Ship Salt Water Mains. Investigation and tests on this subject have been under way since March, 1926, and are still in operation on various test samples of pipe materials which were installed in duplicate so as to subject the test pieces to both hot and cold salt water separately.

Test pipes each five feet long and averaging two and one-half inches in diameter are connected in parallel between two large wooden tanks which act as headers. Sea water at existing temperatures flows into one header to a constant head of five feet, flows through the test pipes into the other header to a depth of five feet and overflows into the sewer. Sea water at a temperature of approximately 150 degrees F. flows similarly through the

duplicate installation. About 7500 gallons flows through each installation every twenty-four hours.

The test pipes are examined daily for any evidence of leakage and the two installations are periodically drained and flushed to remove any sediment which has collected, at which time the interior of the pipes are examined from each end and a record made of their condition before continuing the test.

The following list shows the material of the piping under test:

Black, butt weld steel pipe.
Galvanized steel pipe.
Black lap weld steel pipe.
Galvanized steel pipe.
Black steel pipe.
"Enduro" black pipe.
Black wrought iron lap weld pipe.
Black copper steel pipe.
Galvanized wrought iron pipe.
Black Ascoloy steel pipe.
Black "Everdur" pipe.
Black wrought iron pipe.
Black 1 per cent copper steel pipe.
Low brass 80-20 pipe.
Red brass 85-15 pipe.
Nickel "A" pipe.
Copper pipe.
Brass pipe.
Leadized steel pipe.
Leadlined steel pipe.
"Alpha" brass pipe.
Copper bearing wrought iron pipe.

Bearing Metals. For the purpose of making relative tests of the efficiency and wear of bearing metals, a special apparatus was developed. This apparatus employs a 10 square inch bearing of the metal under investigation, on which varying loads can be placed. It was specially built by the Riehle Testing Ma-

chine Co. and is one of the few machines of this type in existence. It is equipped with a large motor driven horizontal shaft, 6 inches in diameter at the bearing test section. This shaft rotates at a speed of 250 revolutions per minute. The bearing metal under test rests on the upper surface of the shaft at its center and is supported in a yoke. By means of knife edge supported levers any load from 50 to 2000 pounds per square inch can be applied to the bearing metal and regulated amounts of lubricants can be fed to the bearing. The test bearing is operated under various loads or pressure until constant temperature is reached. From the load applied and the characteristic constants of the machine the coefficient of friction is computed. This apparatus has proved to be of considerable value in evaluating different metals with respect to their suitability for use in bearings.

Valve Springs, Exhaust, Diesel Engines. Considerable trouble was experienced in building Diesel Engines at the Navy Yard, New York, due to the breakage of exhaust valve springs. The apparatus shown (Figure 20) was constructed for the purpose of conducting tests on this material. Springs submitted for inspection are subjected to repeated compressions until the spring is solid, at the rate of 500 compressions per minute until breakage occurs. As a result of these tests, it has been found that springs made of suitable material properly designed and heat treated can stand a minimum of from 1,000,000 to 5,000,000 compressions, depending upon the size of the spring. Samples from deliveries are subjected to the above tests and are required to withstand the minimum number of compressions for the particular size. The best results obtained up to the present time for a "5,000,000 compressions" spring was 18,809,755 compressions on a spring of the following dimensions:

Length open 8–7/16 inches.
Length solid 5–1/8 inches.
Diameter 3–9/16 inches.
Diameter of spring wire .375 inch.
Number of turns 10 free, 12 total.
Material. Chrome Vanadium Steel.

CORROSION RESISTING METALS AND COATINGS.

For these investigations and tests, a salt spray apparatus is used.

For large test specimens, such as metal plates covered with a protective coating, two tanks are used, one of soapstone, the other of porcelain-lined metal. Each tank is fitted with four nozzles that atomize the saline solution and fill the tanks with a very fine fog. A 20 per cent salt solution is used.

For small test specimens, a large glass cheese cover is placed over a pool of 4 per cent salt solution which is atomized by a single nozzle. This piece of equipment is specially used for testing corrosion resisting steels as required by specifications.

During the day the navy yard compressed air system is used to produce the spray, reducing the line pressure of 100 pounds to about 4 pounds pressure. Due to the fact that the navy yard system is shut down at night, the small motor driven air compressor shown delivering 4 pounds pressure is used to furnish the air required for continuous tests.

METALLOGRAPHIC DETERMINATIONS.

For these investigations and tests, a Leitz Macro-and-Micro-Metallographic equipment of the latest design has been purchased recently.

It consists of a horizontal camera with 40 inch bellows extension, automatic time and instantaneous shutter, ground glass screen and mirror and 8 inch $\times$ 10 inch plate holder adapted also for 4 inch $\times$ 5 inch plates; an inverted microscope, with mechanical stage, for low, intermediate and high magnifications of 75, 100, 150, 200, 250, 300, and 500 diameters; and a vertical illuminator with ray filters and liquid solution filter trough; the source of light is a 5 ampere 110 volt arc lamp with automatic constant feed. All units are mounted on a solid triangular metal optical bed attached to a vibration absorber, which is hung by spiral springs from a wooden base plate. A simple lever movement lifts the optical bed free from the wooden base plate and renders the equipment vibrationless without the need of an expensive concrete foundation.

PHYSICAL PROPERTIES OF METALS.

The Laboratory is equipped with the usual apparatus for determining tensile strength, yield point, elongation and reduction of area up to 200,000 pounds, actual breaking tensile strength. In addition, there has been added recently an Amsler Impact Testing Machine.

This machine is designed for making three kinds of tests:

(a) Transverse Impact Tests (Charpy method).
(b) Tensile Impact Tests.
(c) Cantilever Impact Tests ("Izod" method).

The capacity of the machine is 120-foot pounds.

This instrument has been used to determine the resistance offered by armor bars to impact of projectiles and projectile fragments.

The following items are part of the equipment used in investigating the physical properties of metals.

18 inch × 14 inch × 8–1/2 inch electric furnace, in the walls are placed " U" shaped chromel heating units by means of which temperatures can be obtained up to 2000 degrees F. The temperature is maintained within ± 6 degrees F. by means of a Hoskins Automatic Temperature Regulator in connection with an indicating thermometer and a platinum platinum–rhodium thermocouple within the furnace. Blue, white and red pilot lights indicate respectively whether the temperature is below, at or above the exact desired temperature. The temperature of the furnace may also be regulated approximately by varying the electrical input to the furnace by a selective switch connected to the secondary of the power transformer.

A 22 inch × 3 inch diameter electric carbon ring resistance furnace in which temperatures can be obtained up to 3000 degrees F. Regulation of temperature is manually controlled by varying the compression between the carbon rings by means of two compression screws at the front of the furnace.

Polishing table, for preparing metal specimens for microphotographic examination. Two 1/2 H.P. motors directly connected to vertical shafts drive a 10 inch diameter horizontal polishing

disc. These discs are interchangeable and are covered with various types of material, such as duck, broadcloth, etc., which are coated with various grades of polishing material. Through adjustable resistances, any desired speed of rotation up to 1750 R.P.M. may be obtained. This table was designed and built by the laboratory personnel.

Aging of Rubber and Rubber Compounds. Extensive tests have been conducted in determining the longevity qualities of rubber used as gaskets for watertight doors, deck plates, manhole covers, etc. To accelerate these tests a Despatch electric oven was purchased.

It has a heating chamber 33 inches × 24 inches × 18 inches. It operates at 220 volts at a maximum of 12 amperes. It has double sheet metal walls, enclosing insulating material. Two circular racks for holding test specimens are rotated by a belt drive from an electric motor located on top of the oven. Air, either fresh or recirculated, is driven through the motor at the rate of 4 cubic feet per minute by means of a motor driven fan located on the top of the oven.

Any temperature from room temperature up to 180 degrees C. can be maintained within ± 1 degree C. by an automatic Bristol thermometer control.

Figure 21 shows one of many special pieces of testing equipment of a temporary nature, designed and built in the Laboratory. Its purpose is to test abrasive papers and cloths with a view to obtaining data as to their relative efficiency as indicated by a table of Work Factors.

Each sample of abrasive cloth is attached to a holder, and secured to the side of a long wooden bar which is given a reciprocating motion by an electric motor.

A small bar of steel or brass of 1 square inch cross section of standardized hardness is pressed against each sample of cloth by a wood plunger activated by a hanging weight of 10 pounds.

The samples of abrasive cloth are rubbed against the bars of metal until the rate of cutting the metal, as determined by loss of weight, is reduced to one half of the original speed of cutting, the Work Factors being based on this data.

The Machine Shop. A small machine shop has been established as an essential part of the Laboratory. In this shop, test specimens are machined, jigs and fixtures are made, many pieces of special testing equipment are built and the extensive equipment of the Laboratory is kept in repair.

The machine shop has the following equipment:

1 Motor driven shaper, 18 inch stroke.
1 Belt driven, No. 1, universal milling machine, 3 foot table.
1 Motor driven, No. 3, Morse taper drill press.
1 Motor driven, No. 4, Morse taper drill press.
2 Motor driven, 17 inch power hacksaws.
1 Motor driven, 12 inch power hacksaw.
1 Motor driven engine lathe, 9 inch swing, 72 inch centers.
1 Belt driven engine lathe, 7 inch swing, 72 inch centers.
1 Belt driven engine lathe, 6 inch swing, 48 inch centers.
1 Motor driven Precision Lathe, 13 inch swing, 50 inch centers.

THE GYRO COMPASS SECTION.

The present civilian personnel of the Gyro Compass Section is composed of the following:

1 Associate Material Engineer, Assistant.
2 Assistant Inspectors, Electrical.
5 Electricians, first class.
2 Helpers, Electrician.

(These are included in the total Laboratory personnel of 71.)

Active contracts for material to be inspected and tested by this section cover the following:

26 Compasses and equipment.
24 Dead Reckoning Tracers and Equipment.
38 Self Synchronous Alidades.
16 Self Synchronous Course Recorders.

This section prepares specifications, conducts acceptance tests and experiments on the following list of navigation material for the Bureau of Navigation:

Master Gyro compass, spare sensitive elements for master gyro compass, control panels, repeater compass panels, repeater com-

passes, motor generators, relay panels, spare parts for gyro compass equipment, Dead Reckoning Tracers, Tracking Tables, Repeaters for Dead Reckoning, Latitude and Longitude Indicators, Self Synchronous Alidades, Course Recorders, and Reverse Current Circuit Breakers.

In addition to testing the above new equipment, this section repairs, balances, adjusts and tests all types of gyro compasses and their auxiliary equipment in service.

To accomplish the work listed above, the following equipment is installed:

Four Scorsby Test Stands.

Five Arma and Sperry Control Panels (with the necessary motor generators, control panels, etc.).

Rotor balancing machines for both Arma and Sperry compasses.

Parallel swings for balancing and adjusting Sperry master gyro compasses.

Binnacle stands for various types of master gyro compasses. Control panels (with motor generators to operate the various types of master gyro compasses).

The Scorsby Test Stand is an apparatus upon which a master gyro compass is placed and upon which the compass is subjected to rolling, pitching and yawing, all motions simultaneously or each motion separately.

After each gyro compass equipment is subjected to parts inspection at the works of the manufacturer, each master compass and its spare sensitive element must be subjected to Laboratory acceptance tests as follows:

Part 1. Control Panel.
Part 2. Variation in Supply Voltage.
Part 3a. Damping (West).
Part 3b. Damping (East).
Part 3c. 20-Hour Turn-Table.
Part 3d. 48-Hour Small-Angle Scorsby.
Part 3e. 48-Hour Large-Angle Scorsby.
Part 3f. Undamped Period.
Part 3g. Damping Eliminator.

Part 4. Repeater Compass.
Part 5. Power Apparatus.
Part 6. Correction Device.
Part 7. Insulation.

The master compass is placed upon the Scorsby test stand (which shall then be on zero heading), and secured, after its lubber line has been made parallel to the established meridian. The binnacle is spaced above the stand so as to have the center(s) of the gyro(s) not less than 35 inches above the center of motion of the stand. The latitude correction is then made, if design of master compass permits. The master compass is then turned over to the contractor who connects it with its complete equipment, and gives it a preliminary run to insure that it is properly adjusted and in good operating condition. The master compass and its equipment is then turned over to the Laboratory which checks the operating conditions as enumerated below in so far as the design permits.

After the contractor has made all the adjustments as stated above, the master compass must pass through the entire acceptance tests without being opened for any purpose, except for starting up and shutting down over holidays and week ends, and except as necessary to check the Scorsby connections to the compass in case of electrical trouble. Any failure, breakdown, or adjustment of any part of the master compass, including the binnacle, its fittings and everything within it (except illuminating lamps), at any time during the entire acceptance tests, necessitates restarting the entire acceptance tests.

During normal test conditions, not over 4 hours is allowed for the compass to settle. Should the compass not arrive at a settling point within a period of 4 hours, it is considered to have failed and the test must be restarted. Two hours additional is allowed, when starting up, for the compass to attain a normal operating temperature.

A master compass and its equipment which fail to pass the official acceptance tests after 3 months' time from the beginning of the first test, shall, without cost to the Government, be removed from the Laboratory by the contractor and given a complete over-

haul at the factory under the supervision and to the satisfaction of the Inspector of Navigational Material, before it may again be submitted for test.

The A. C. voltage shall be between 110 and 130 volts. The A. C. amperes shall be between 1.5 and 3 amperes. The D. C. voltage shall be between 113 and 117 volts. The D. C. amperes shall be between 5 and 10 amperes;

The amplitude of "hunt" shall be between 1/4 degree and 1/2 degree.

The speed of the rotor or rotors shall be between 4000 and 12,000 R.P.M.

Where rotors operate in a vacuum, the vacuum shall not be less than 24 inches under all temperature conditions;

The supply voltage shall not vary more than ± 2 volts from the normal voltage of the equipment throughout the entire acceptance tests, except as necessary in conducting the "Variation in Supply Voltage" test.

A short description of the more important tests and the allowed errors follow.

Variation in Supply Voltage. The supply voltage is suddenly changed 10 per cent, as indicated in the table below. The master gyro compass is allowed to settle under this new condition of operation. During the 4 hour period allowed for the compass to settle, 15 minute readings of the master gyro compass are taken to determine the master compass error at all times during this period. The maximum errors of the master gyro compass must not exceed values as shown in the table.

Change in Voltage		*Maximum Error in Reading*	*Maximum Settling Point Error*
From	To	Degrees	Degrees
Normal	Normal + 10 per cent	0.25	0.20
Normal + 10 per cent	Normal	0.25	0.20
Normal	Normal — 10 per cent	0.25	0.20
Normal — 10 per cent	Normal	0.25	0.20

48-Hour Large-Angle Scorsby. The master compass is given a 48-hour large-angle Scorsby test after it has settled. No adjust-

ment shall be made on the cardan dampers to reduce the swing of the sensitive element. The master compass shall then be tested on the following true headings:

Time	*Heading*	*Condition*
4 hours	Any Cardinal	Roll, Pitch, Yaw
2 hours	Any Cardinal	Roll
2 hours	Any Cardinal	Pitch
4 hours	Any Cardinal	Roll, Pitch, Yaw
2 hours	Any Cardinal	Roll
2 hours	Any Cardinal	Pitch

Time	*Heading*	*Condition*
4 hours	Any Intercardinal	Roll, Pitch, Yaw
2 hours	Any Intercardinal	Roll
2 hours	Any Intercardinal	Pitch
4 hours	Any Intercardinal	Roll, Pitch, Yaw
2 hours	Any Intercardinal	Roll
2 hours	Any Intercardinal	Pitch
4 hours	Any Semi-Intercardinal	Roll, Pitch, Yaw
2 hours	Any Semi-Intercardinal	Roll
2 hours	Any Semi-Intercardinal	Pitch
4 hours	Any Semi-Intercardinal	Roll, Pitch, Yaw
2 hours	Any Semi-Intercardinal	Roll
2 hours	Any Semi-Intercardinal	Pitch

The total amplitude of roll is 80 degrees with a period between 8 and 9 seconds. The total amplitude of pitch is 20 degrees with a period between 6 and 7 seconds. A natural yaw is introduced from the combination of roll and pitch, due to the design of the Scorsby test stand, so no additional yaw is necessary. A reading of the master compass is recorded every half-hour. To obtain an accurate reading the Scorsby is stopped, trammed and brought to a vertical position. The error on any heading shall not exceed 1 degree on either side of the established meridian.

Insulation. The master compass and its complete equipment is given an insulation test of 1000 volts A. C. while in operating condition (hot); however, in a compass in which the gyro(s) is designed to be operated in a vacuum, the test of insulation in

the vacuum chamber shall be at 400 volts A. C. with a vacuum of 28 inches and at 1 000 volts A. C. with the vacuum relieved.

Dead Reckoning Tracer Equipment is subjected to the following tests:

Distance and Direction.
Turn.

The acceptance tests are conducted on a Scorsby test stand or on any other suitable apparatus.

Distance and Direction. (a) With the plotting unit in operation and the "ship's head input" at any heading and the equipment set for any number of revolutions per mile within those specified by the contract, and the plotting point at one end of the chart, operate the revolution transmitter at a speed corresponding to any ship's speed within the specifications until the plotting point approaches the limit of the chart, the total revolutions of the transmitter being recorded by a counter. The above shall be performed with the propeller shaft going ahead.

(b) Repeat (a) with the "ship's head input" set on any heading at right angles to the heading used in (a).

(c) Operate on various different plotting scales as provided by the contract to insure that motors have sufficient power to drive the plotting point at maximum rate of travel.

(d) Under (a), (b), and (c), the distance is computed according to the scale in use and compared with the distance actually plotted on chart. The difference shall not exceed 1 per cent. Under (a), (b), and (c), by the use of a protractor on the chart, the angular difference is determined between the line of advance and the true heading as obtained from the ship's head input. The difference shall not exceed one-half 1/2 degree.

Turn. (a) With the revolution transmitter stopped, the "ship's head input" shall be varied at a constant rate not faster than 2 degrees per second for a total charge of 720 degrees first in one direction, then in the other. The revolution transmitter shall then be operated to plot a line sufficiently long so that its direction may be determined.

(b) The foregoing test shall not cut, tear, nor unduly abrade the plotting paper and the final line plotted shall not vary more than 1 degree from the "ship's head input."

At various times during the preceding outlined tests, the plotting unit and any other unit which might possibly be affected by changes in position shall be tilted to various angles with the horizontal from 0 degree to 90 degrees.

In case the design of the equipment is such as to make it appear desirable, any of the foregoing tests shall be repeated with the plotting unit or other unit mounted on a Scorsby test stand which shall be operated with a total amplitude of roll of 30 degrees with a period between six and ten seconds and a total amplitude of pitch of 10 degrees with a period of between eight and twelve seconds.

Self-Synchronous Alidades are subjected to the following tests:

Azimuth.
Water Tightness.
Illumination.

Azimuth. The equipment is centrally mounted on a Scorsby test stand, which shall remain vertical, the lubber lines being made parallel. The electrical connections are made, the repeater motors being operated from transmitters positioned by the rotation of the Scorsby. The vertical cross-wire of the telescope is directed on the middle one of three vertical wires suspended in the test room. The Scorsby shall then be rotated in a variety of ways; provided that the rate of rotation shall never exceed 90 degrees per minute. The vertical cross-wire of the telescope must never reach either of the outer vertical wires, which are separated 1/10 degrees from the center wire. The test is conducted for 48 hours with observations every half-hour or oftener. At no time must the reading dials differ from the Scorsby heading by as much as 3/100 degrees.

Water Tightness. The assembled case is placed in a suitable container and immersed in tap water one to two inches above the highest point on the case and allowed to remain 24 hours. It is then dried externally, opened, and examined for internal moisture of which it must show no indication.

Illumination. The instrument, fully illuminated, is viewed from various directions from a distance of 10 yards, against a dark background, on a dark night with clear atmosphere, extraneous

light being so little as not to influence the result. The instrument must be invisible. At the same time an observer at the instrument shall determine that the illumination is adequate to the efficient operation of the equipment.

The Scorsby Test Stands and Controls are shown in Figure 22.

SOUND MOTION PICTURE EQUIPMENT FOR THE NAVY.

By Lieut. H. C. Rule, U. S. Navy, Member.

Many and various are the reasons for the Navy's adopting the use of sound motion picture equipment for supplying shipboard entertainment. For the past two and a half years this form of entertainment has been displayed in thousands of theaters in this country with an increasing popularity and a steady rise toward mechanical perfection. This increasing success of the "talkies" has practically revolutionized the motion picture industry—at least to the extent of reducing the production of silent motion pictures to an astonishingly low number. Thus the ultimate discontinuance of silent film production may readily be visualized and if the Navy continues the use of this form of entertainment it will be forced to accept a limited number of films at a comparatively exorbitant price.

Furthermore, by adopting the use of "talkies," the Navy has availed itself of the most modern and up-to-date method of advancing education to both the officers and the enlisted men. This method of aural and visual education which will depict, explain and discuss as the picture progresses, opens a field to the presentation of problems heretofore unmentioned because of the previous lack of background or the proper authority to give the discussion. Problems dealing with machine shop practice or fleet maneuvers may be presented and discussed to the complete satisfaction and understanding of all interested.

But the adoption of "talkie" equipment was not a result of the fine equipment that was produced for motion picture theaters. The theater equipment was entirely unsuitable for shipboard use. It was delicate, fragile, and subject to failure when disturbed by shock or vibration and particularly when in contact with salt air and spray. It was an ideal equipment for the purpose intended but it was never intended for use on shipboard. The true reason

for its introduction into the Navy was its demand by the Service. Practically every ship and station wanted "talkies." But before "talkies" could be supplied it was necessary to develop an equipment that would withstand sea conditions and thus assure satisfactory projection without interruption of the program due to mechanical or electrical failure.

Thus it fell to the Bureau of Engineering to investigate and study the art of sound projection with a view to adapting its use to the Navy afloat. This was a tremendous problem. There were no specifications available to consult and none of the manufacturers of sound motion picture equipment had contemplated the use of such apparatus on board ship. It was a new application of a new art and there was no one who could definitely state the outcome of any suggested arrangement. It was therefore decided to start at the very beginning and work along slowly and carefully, step by step, until a definite conclusion was reached in each case and every obstacle unquestionably overcome.

There are two types of sound motion picture reproducing apparatus and three systems of sound recording. The sound-on-disc type apparatus employs a disc record carrying the sound track separate from but operated in mechanical synchronism with the film, while the sound-on-film type, adopted by the Navy, employs the use of the sound track on the film. There are also two methods of producing the sound track on the film. These methods are known as the variable area method and the variable density method, either of which may be used with the Navy equipment. The variable area sound track has the appearance of an oscillograph record which it essentially is (See Figure 2, Plate G), while the variable density sound track appears as a series of light and dark horizontal strips varying in width and density across the sound track (See Figure 1, Plate G). In either case the sound track is 4 millimeters in width.

The sound motion picture reproducing apparatus consists of a motor-driven projector which carries the sound head, a voltage amplifier, a power amplifier, and projection speakers. The projector places the picture on the screen and feeds the film through the light gate and the sound gate of the sound head at a steady

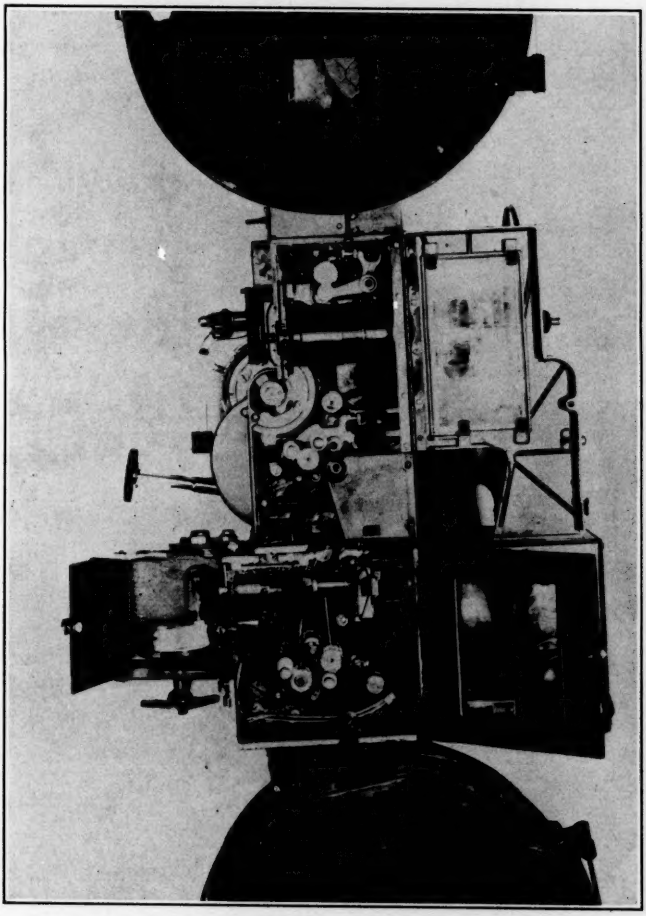

PLATE A.

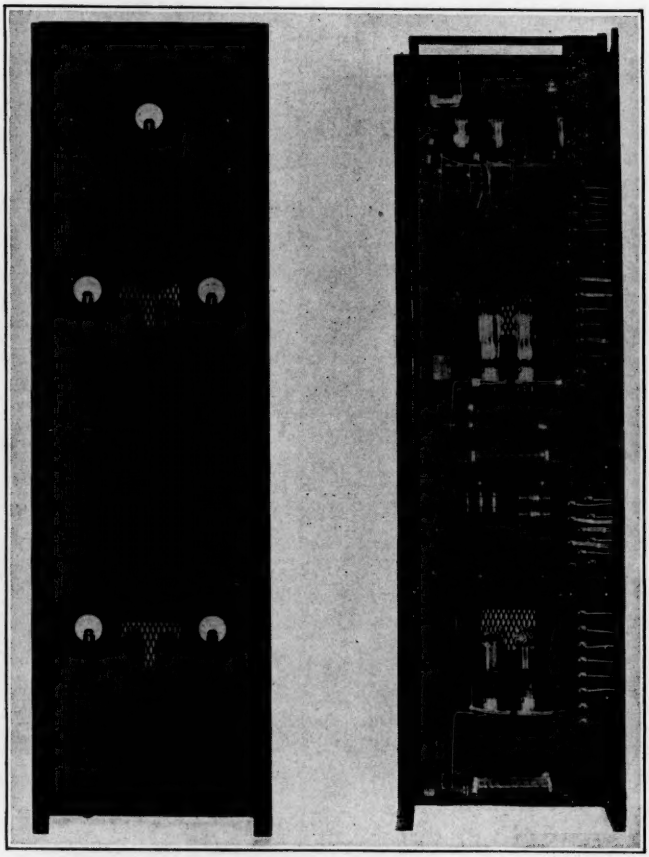

PLATE B.

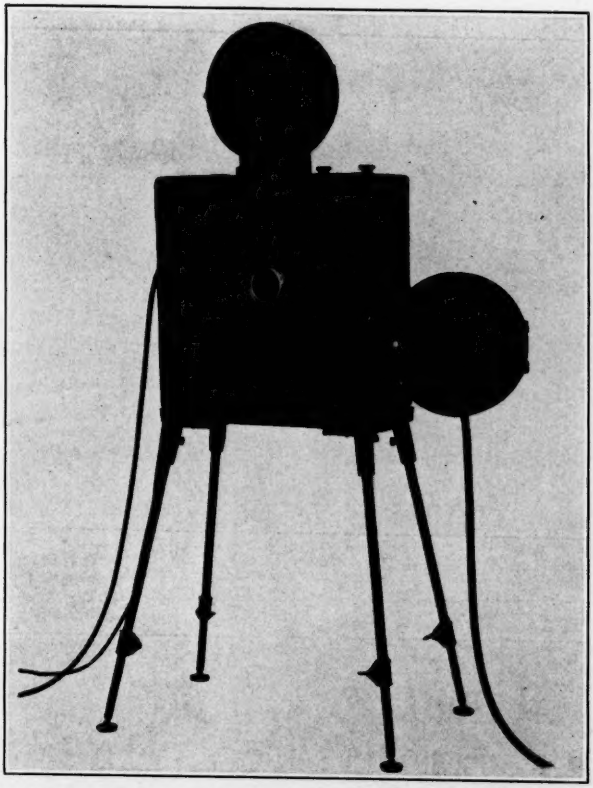

PLATE C.

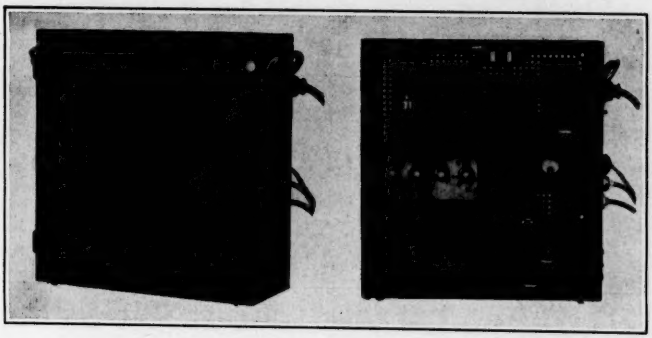

PLATE E.

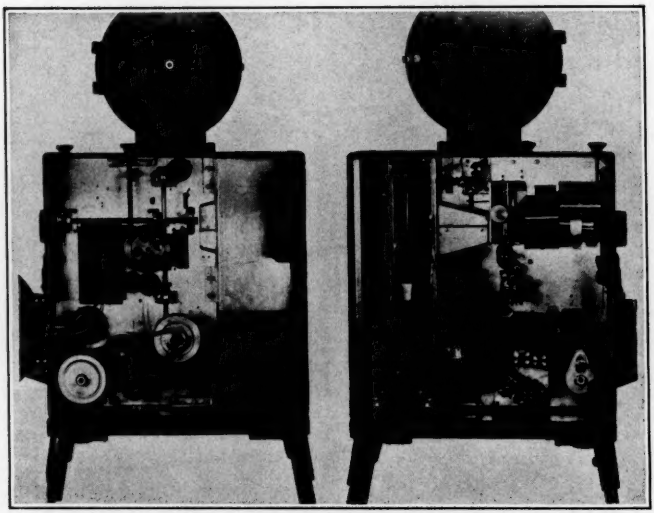

PLATE D.

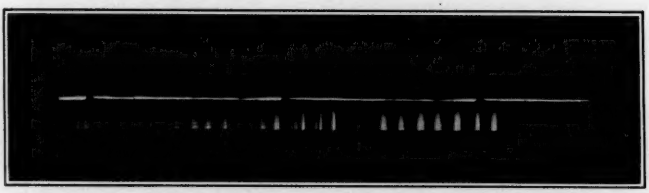

FIG. 1.

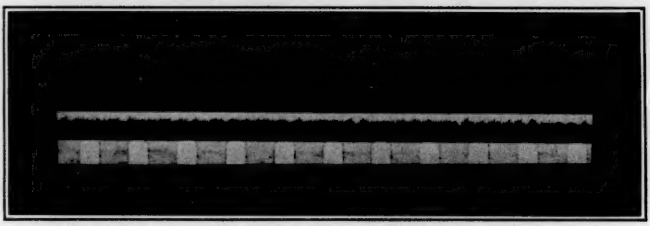

FIG. 2.

PLATE G.

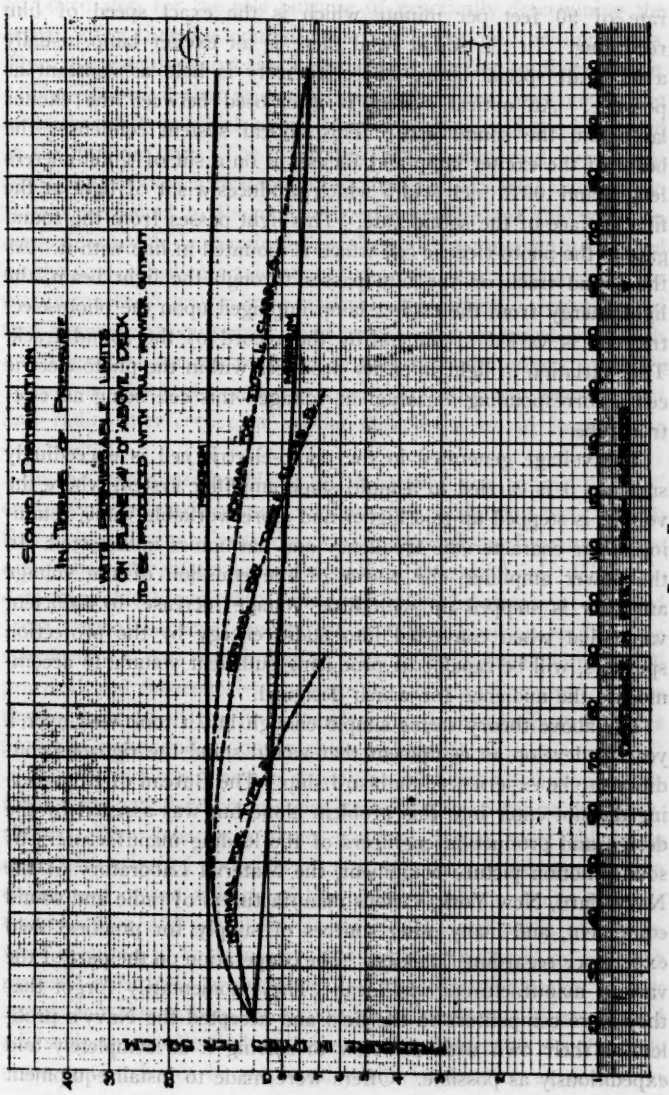
Sound Distribution
In Terms of Pressure
With Practicable Limits
On Plane 4'-0" Above Deck
To Be Produced With Full Power Output
Normal for 20th Century Theatre
Normal for 20th Century Theatre
Normal for 20th Century Theatre
Pressure in Dynes per Sq. Cm.

PLATE F.

rate of 90 feet per minute which is the exact speed of film recording. In the sound head there is an exciter lamp, usually a 50 Watt special lamp, whose intensity is held as constant as possible. An optical system is interposed between the exciter lamp and the sound gate. This optical system condenses the beam of the exciter lamp and focuses it on a slit of 4 millimeters length and .0015 inch width which produces a slit of light at the film surface of the sound gate. This light passes from the sound gate to the photo-electric cell which is mounted in line with it. As the sound track on the film passes through the light beam, the light energy from the exciter lamp impinged upon the photo-electric cell is varied in lumens by the record of the sound track. This variation in light intensity produces within the photo-electric cell a corresponding variation in voltage—this cell being an electron tube.

The voltage generated in the photo-electric cell is exceedingly small so it is carried to a multi-stage amplifier system where the voltage is stepped up to a higher and more workable value, retaining all its characteristic frequency and harmonics undistorted. In the power amplifier, the power of the emission of the voltage amplifier is stepped up with little voltage increase, to sufficient value that when converted into audio energy by the projection speakers, will be capable of producing sufficient volume to accommodate the audience for which designed.

The above theory seems simple enough but it took well over a year to develop an equipment that would stand the rigorous conditions to be experienced on board ship. The Bureau of Engineering did not enter into this problem alone but was assisted by the design and production engineers of the leading manufacturers of sound motion picture equipment, the Material Laboratory of the Navy Yard, New York, various manufacturers of radio and sound equipment, and many other sources of supply for practical field experience regarding "talkies." The cooperation on the part of the various manufacturers was ideal. They momentarily forgot that they were competitors in the field and accepted the Navy's problem as their own with the view to solving it as completely and expeditiously as possible. Offers were made to install equipment

on board ship for the sole purpose of practically determining the actual effect Service conditions would have on the apparatus. Thus the tests on board the *Texas* during the last southern cruise.

The equipment that was installed on the *Texas* was one of the large theater type which at the time was considered the last word in the "talkie" art. The apparatus was accompanied by a Company engineer and a representative from the Material Laboratory. It was subjected to the normal routine conditions that such an equipment would be required to withstand if permanently installed on the ship. For entertainment purposes it was a failure, but for test purposes, it was a huge success. It practically demonstrated that commercial equipment could not be used on board ship, with any degree of success and that to withstand the effects of ship's vibrations, shock of gunfire, rain, salt air and spray, tropical heat and radio interference, a special equipment would have to be constructed.

In the meantime the Material Laboratory was testing "talkie" equipment and devising new methods for conducting tests. With the arrival of the *Texas* data, minimums of performance were established and material and design requirements fixed. With this data available along with reams of other information obtained from various sources, the Bureau was in a position to draw up specifications for sound motion picture equipment with a full practical and theoretical knowledge of what was required. Thus the compilation of the first complete purchase specifications ever prepared for sound motion picture equipment.

Every effort was made to specify an apparatus that would conform to the standard commercial equipment in so far as was practicable. The departures from standard design were chiefly in material, design of sound head, size and number of reproducers, design and output voltage of the power amplifier, along with the weight, space, and portability factors. All metal parts, of course, were required to be of a corrosion resisting material or of other material effectively protected against the corrosive action of salt spray, salt atmosphere, or exposure to weather. It was found advisable to require that no wire smaller than 1600 circular mils cross sectional area be employed where its location exposes it in

any way to the corrosive action of salt air and humidity. It was further found necessary to require that the apparatus in the sound head with the exception of the photo-cell and any amplifier tubes and sockets therein be completely submerged in pitch or other suitable material to insure its water-proofness. The reproducers or loud speakers must be capable of ready portability and easy handling to facilitate attachment to the screen support and readily stowable after the performance. The number of reproducers required is entirely dependent upon the number necessary to meet the sound pressure level and distribution as shown on the chart on Plate F. The total power output of the power amplifier must be such as to excite the loud speaker units to a maximum sound volume corresponding to the values shown on the plate. The amplifiers, of course, must be of such dimensions as to be capable of passage through hatches on board ship.

There are three classes of equipment to be used in the Navy. Type I, Class A equipment is designed for battleship, carrier, and large shore station use. It consists of a professional arc type projector with sound head attached (See Plate A). This projector is to be mounted in a booth which will be either fixed or made portable by the use of wheels or rollers. The amplifiers are to be mounted on panels below decks in a location as free from shock, vibration, and salt atmosphere, as is possible. Plate B shows an amplifier of similar design to that which will be employed for use with the Type I, Class A equipment. The number of speakers for each equipment is dependent upon the size of the ships' average audience and the area of the deck space to be covered. The speakers for all classes of equipment are of the same size and type—the only difference between sets being the number employed. Likewise the screens for all classes of equipment are the same except for size. The screens will have a strength comparable to sail cloth, will allow the passage of sound at 1000 cycles through them with a cut off not exceeding ten per cent, and will withstand the prolonged effects of salt atmosphere, salt spray, and rain as well as fuel oil soot with a high sulphur content. Furthermore they will be readily adaptable to washing in fresh or salt water.

Type I, Class B equipment is designed for cruisers and auxiliary ship use and consists of a portable projector as shown on Plates

C and D, amplifiers mounted on panels below decks similar to that shown on Plate B but with less power output and the speakers and screen as described above. The Type II equipment is designed for destroyer and small ship use as well as for small shore stations with an audience of one hundred or less. It consists of a portable projector, the same as the cruiser type shown on Plate C and D, a portable amplifier as shown on Plate E, one speaker and the screen.

It is felt that the work in the art of sound motion picture projection has just begun and that after the equipment already contracted for has been subjected to Service use, occasional improvements will be necessary to maintain the high standard of performance that is expected of the apparatus. These improvements are predicated upon the cooperation of the forces afloat in supplying constructive criticism regarding design and operating features of the equipment, as well as the results emanating from the continued study of the subject by the Material Laboratory, Navy Yard, New York.

DISCUSSION.

THE BALANCING OF ROTATING MASSES.

DISCUSSION OF PAPER BY LIEUTENANT H. G. EBERHART, U.S.N., MEMBER, IN NOVEMBER 1930, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

BY LIEUTENANT F. A. TUSLER, (C.C.) U.S.N., MEMBER.

In keeping with the spirit of Lieutenant Eberhart's paper "The Balancing of Rotating Masses" to create a better understanding of rotative balance, it is hoped that the following remarks will clear up some obscure points and correct certain inaccuracies of statement.

In the last paragraph, p. 585, the author evidently means "transverse plane" wherever the term "axial plane" appears.

The use of "l" in Figures 15 and 16, p. 586, for two different distances is rather ill advised, since the "l" in the equations on p. 586 refer to Figure 15, whereas the "l" throughout the remainder of the paper refers to Figure 16. Both distances enter into the equations involved in the solution of any problem. It is suggested that the distance between bearings be changed to "L". The equations on p. 586 are likely to lead to confusion due to the occurrence of "a" on both sides of the first equation, that of "b" on both sides of the second; the first use in each case as a subscript, the second as a factor. In view of the above, it is suggested that these equations be made to read as follows: (using "L" for the distance between bearings):

$$R_a = \frac{F_1.a}{L} \text{ and } R_b = \frac{F_2.b}{L}$$

Up to and including p. 586, the word "force" has been used in its true sense, *i. e.*,

$$F = M.\ a = \frac{W}{g}.\ \omega^2.r$$

where,

ω = angular acceleration.

g = acceleration, due to gravity.

In the matter following p. 586, the term $\frac{\omega^2}{g}$ has been dropped out. This is permissible because all points of the body rotate at the same angular velocity and the centrifugal forces arising from the various unbalanced masses are always in the same ratio; each force is proportional to the product of its weight by its radial distance from the axis. The gravity constant is common to all forces at all speeds.

The statement on p. 588, "Should it be desired, for any purpose, to separate the static and the dynamic corrections, R_a and R_b represent the static forces while the dotted lines in Figure 17 (a) and (b) represent the dynamic forces." is, unfortunately, not in accordance with the facts. This will be clear from a reference to Figures 14, 15, 16, and 17 of the basic paper. From Figure 14 it will be noted that the static correction must be made in the axial plane of S and the dynamic correction in the axial plane of D. The force R of Figure 14 lies in some axial plane *between* these planes, determined by the relative magnitudes of G and Q. Though not so stated by the author, force F_1 of Figure 15 is equal to, but opposite from force R of Figure 14 and lies in the axial plane of R. R_a of Figures 15 and 16 lies in the axial plane of F_1. Also, R_{a1}, Figure 16, lies in the axial plane of R_a. Following the author's nomenclature, the force R_a of Figure 17 should evidently read R_{a1} as this is the force R_{a1} of Figure 16. Hence it follows that R_{a1} (R_a of Figure 17) *does not* lie in the static plane, except in the special case where the static and dynamic planes are coincident. This seldom occurs. The author has evidently assumed that, because the "broken lines" of Figure 17 (a) and (b) are equal and parallel, these represent the amount of the dynamic correction. The lines are necessarily equal and parallel from the nature of their construction, but are never equal to the dynamic correction in amount and are only parallel to its plane in the special case of coincident static and dynamic planes. The determination of the static and dynamic components of unbalance is impossible unless the axial location of the center of gravity of the rotor is known.

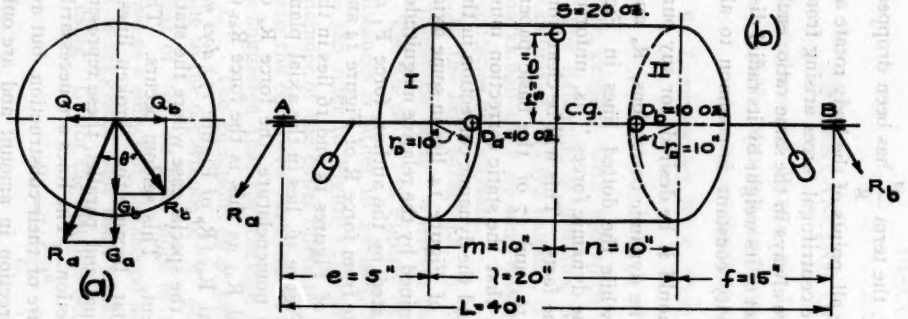

FIG. 1

$G_a = \frac{S \cdot r_s (n+f)}{L} = \frac{20 \times 10 \times 25}{40} = 12.5$ IN. OZ. $\quad Q_a = \frac{D_a \cdot r_a \cdot l}{L} = \frac{10 \times 10 \times 20}{40} = 50$ IN. OZ.

$G_b = \frac{S \cdot r_s (e+m)}{L} = \frac{20 \times 10 \times 15}{40} = 75$ IN. OZ. $\quad Q_b = \frac{D_b \cdot r_b \cdot l}{L} = \frac{10 \times 10 \times 20}{40} = 50$ IN. OZ.

R_a (RESULTANT OF G_a AND Q_a) = 135 IN. OZ.

R_b (RESULTANT OF G_b AND Q_b) = 90 IN. OZ.

$M_{1a} = R_a \times \frac{e}{l} = 135 \times \frac{5}{20} = 33.75$ IN. OZ. $\quad M_{2b} = R_b \times \frac{f}{l} = 90 \times \frac{15}{20} = 67.6$ IN. OZ.

R_I (FROM FIG. 3) = 141.4 IN. OZ. $\quad R_{II}$ (FROM FIG. 3) = 141.4 IN. OZ.

$W_I = \frac{R_I}{r_I} = \frac{141.4}{10} = 14.14$ OZ. $\quad W_{II} = \frac{R_{II}}{r_{II}} = \frac{141.4}{10} = 14.14$ OZ.

FIG. 2

As further proof of the above, a simple concrete example has been worked out and is presented here as Figures 1, 2, and 3. Using the previous author's nomenclature and referring to Figure 1(a), the dynamic unbalance consists of the equal and opposite weights D_a and D_b, of amount and location as shown; the static unbalance of the weight S. By inspection, it is readily seen that the dynamic correction weight in transverse plane I is $D_I = 10$ ounces; that in plane II is $D_{II} = 10$ ounces—both located as shown in Figure 2(b). The static correction weight in plane I is $S_I = 10$ ounces; that in plane II is $S_{II} = 10$ ounces. The resultant of S_I and D_I is $W_I = 14.14$ ounces; that of S_{II} and D_{II} is $W_{II} = 14.14$ ounces (see Figures 2(a) and (c)). The radius for the correction weights has been taken as 10 inches.

In Figures 1 and 3, the forces R_a and R_b, acting at the A and B bearings respectively, have been calculated and the correction weight at each end determined. R_a is the resultant of G_a and Q_a. R_I is the resultant of R_a plus M_{1a} and M_{2b}.

In this connection, the author does not show how the correction weights are to be obtained from the correction forces. If R_I is the resultant correction force in plane I (assuming the factor $\frac{\omega^2}{g}$ has been dropped throughout), and r_I is the radii at which the correction weight is to be located, then the correction weight W_I in plane I is $W_I = \frac{R_I}{r_I}$; similarly, $W_{II} = \frac{R_{II}}{r_{II}}$ is the correction weight in plane II.

In Figure 3, R_I and R_{II} are shown to scale. It is to be noted that the resulting correction weights, W_I and W_{II}, agree in amount and direction with those obtained in Figure 2(a). By drawing the "broken lines" of Figure 17 of the previous paper on Figure 3, it is quite evident that they do not lie in the axial plane of the dynamic unbalance. To scale the broken lines are equivalent to a weight of 5.5 ounces at a radius of 10 inches in correction planes I and II. Therefore, they do not represent the dynamic correction (10 ounces at a radius of 10 inches). Likewise, R_a and R_b do not represent the static correction in amount or direction.

It is realized that the separation of unbalance into its static and dynamic components is mainly of academic interest, but, since the question of its determination has been raised and the literature on the subject is rather meager, the solution may be of interest.

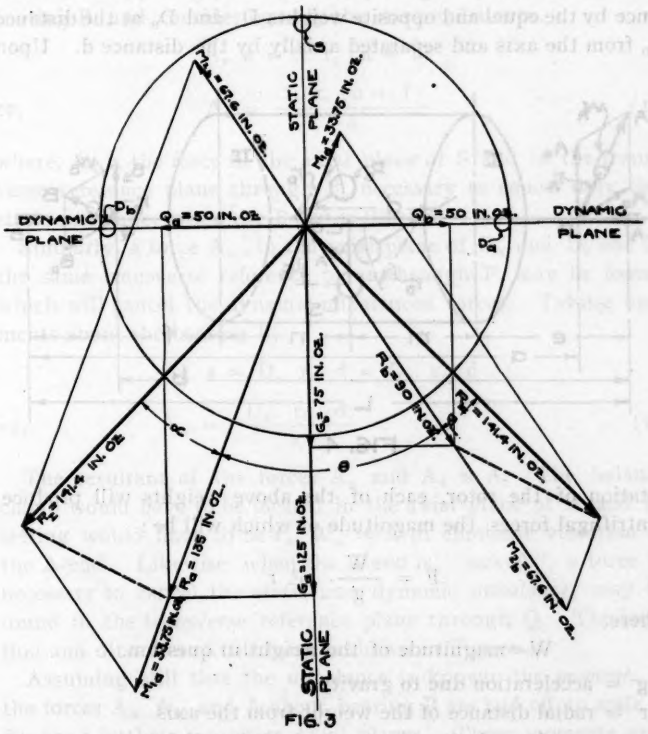

FIG. 3

The following analysis was suggested to the writer by Mr. M. W. Torbet's discussion of the A. S. M. E. paper A.P.M.-50-7, "The Theory of the Dynamic Vibration Absorber" by J. Ormondroyd and J. P. Den Hartog. Mr. Torbet used a rather complicated mathematical analysis to prove the construction used. The present writer's only originality in the matter consists of

the rather simple geometrical proof and the completion of the solution by showing how the correction weights may be calculated from the moment diagram.

In Figure 4 the static unbalance is represented by the weight S at distance r_s from the axis of the shaft in a transverse plane through the center of gravity of the rotor; the dynamic unbalance by the equal and opposite weights D_A and D_B at the distance r_D from the axis and separated axially by the distance d. Upon

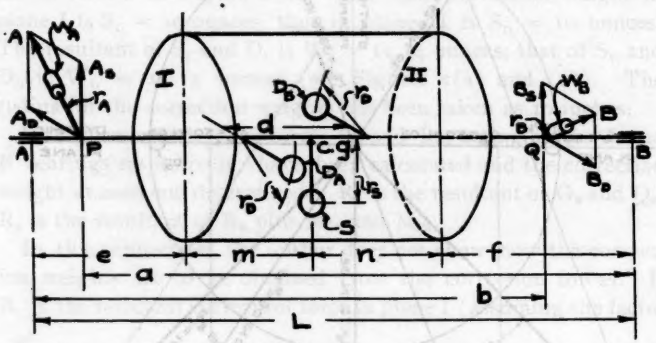

FIG. 4

rotation of the rotor, each of the above weights will produce centrifugal forces, the magnitude of which will be:

$$F = \frac{W}{g} \cdot \omega^2 \cdot r$$

where,

W = magnitude of the weight in question.

g = acceleration due to gravity.

r = radial distance of the weight from the axis.

ω = angular velocity of rotor in radians per second.

As explained above, the factor $\frac{\omega^2}{g}$ may be dropped out and the centrifugal force represented simply by the product of a weight by its distance from the axis.

It is assumed that the rotor is balanced by the usual scheme of locking the bearing at one end and allowing the other end to

"vibrate" and that the unbalance (vibration) is eliminated by means of a balance clamp. The amount and angular location of the unbalanced static and dynamic forces in a transverse reference plane through the balance clamp may be determined as follows (assuming the amount and location of the unbalance to be known). Referring to Figure 4 and taking moments about bearing B, and considering only the static unbalance,

$$A_s . a = S . r_s (n + f)$$

or,
$$A_s = \frac{S . r_s (n + f)}{a} \quad . . . . . \quad (1)$$

where, A_s is the force in the axial plane of S and in the transverse reference plane through P, necessary to cancel only the static unbalance when the B-end is "locked".

Similarly, a force A_D, in the axial plane of D_A and D_B and in the same transverse reference plane through P, may be found which will cancel the dynamic unbalanced forces. Taking moments about the bearing B,

$$A_D . a = D_A . r_D . d = D_B . r_D . d$$

or,
$$A_D = \frac{D_A . r_D . d}{a} \quad . . . . . \quad (2)$$

The resultant of the forces A_D and A_S is A. The balance clamp would have to be located in the axial plane of A and its setting would have to be $r_A . W_A = A$ to eliminate vibration at the A-end. Likewise, when the A-end is "locked", a force B, necessary to cancel the static and dynamic unbalance, may be found in the transverse reference plane through Q. The location and direction of this force is shown in Figure 4.

Assuming still that the unbalance is known, the *moments* of the forces A_S, A_D, and A about bearing B are laid off to scale in Figure 5 in their respective axial planes. These moments are: $A_s . a = S . r_s (n + f)$, $A_D . a = D_A . r_D . d$, and A. a for the transverse reference plane through P.

Similarly, the moments of forces B_S, B_D, and B about bearing A are laid off to scale as shown. If the resultant OG of the moments A.a and B.b be drawn, it will be found to lie in the static plane. In the triangles OMF and GEN,

OM = NG (by construction)
OM ∥ NG (by construction)
OF ∥ EG (by construction)
∴ △ OMF = △ GEN
and, OF = EG
but, OG = OE + EG
or, OG = OE + OF
but, OE = $S.r_s$ (n + f) (by construction)
and, OF = $S.r_s$ (m + e) (by construction)
∴ OG = $S.r_s$ (n + f + m + e) = $S.r_s.L$ . . . (3)

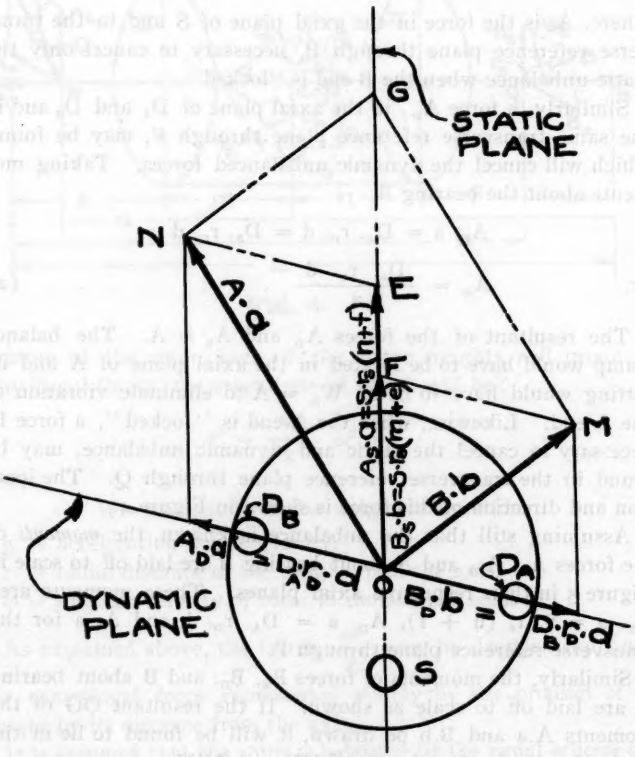

FIG. 5

Returning now to the data actually obtainable from the balancing machine, the force A ($=W_A . r_A$) and its direction are known ; also force B ($= W_B . r_B$) and its direction. The moments A. a and B. b of these forces can be calculated and laid off as shown in Figure 6 in the direction of their respective balance clamps. θ is

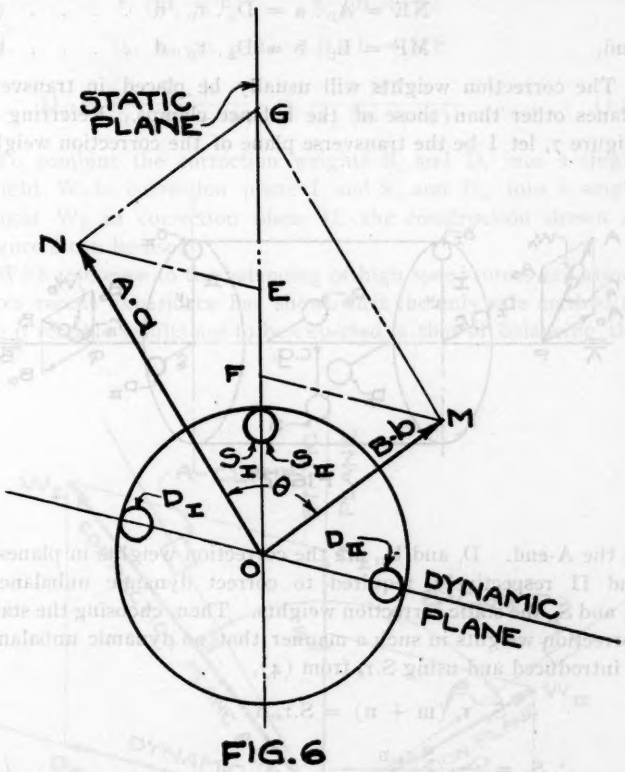

FIG. 6

the angle between the clamps as viewed from the A-end. The resultant OG of A.a and B.b is drawn by completing the parallelogram of moments. The direction of OG determines the static plane. From Equation (3),

$$S.r_s = \frac{OG}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Calculate OE = $S.r_s\ (n+f)$ and plot E. Calculate OF = $S.r_s\ (m + e)$ and plot F. Join points F and M and points N and E. MF and NE determine the amount and plane of the dynamic unbalanced couple. The dynamic plane may now be drawn in through O parallel to MF and NE. In Figure 5,

$$NE = A_D \cdot a = D_A \cdot r_D \cdot d \quad . \quad . \quad . \quad . \quad (5)$$

and,

$$MF = B_D \cdot b = D_B \cdot r_D \cdot d \quad . \quad . \quad . \quad . \quad (6)$$

The correction weights will usually be placed in transverse planes other than those of the balance clamps. Referring to Figure 7, let I be the transverse plane of the correction weights

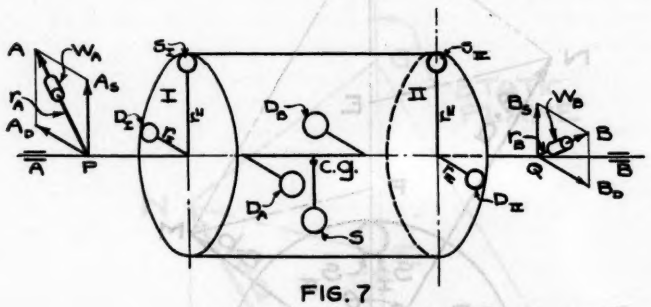

FIG. 7

at the A-end. D_I and D_{II} are the correction weights in planes I and II respectively, required to correct dynamic unbalance; S_I and S_{II} the static correction weights. Then, choosing the static correction weights in such a manner that no dynamic unbalance is introduced and using $S.r_s$ from (4),

$$S_I \cdot r_I\ (m + n) = S.r_s.n$$

$$\therefore S_I = \frac{S.r_s.n}{r_I\ (m + n)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$S_{II} \cdot r_{II}\ (m + n) = S \cdot r_s \cdot m$$

$$\therefore S_{II} = \frac{S \cdot r_s \cdot m}{r_{II}\ (m + n)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The couple due to the dynamic correction weights must equal the couple due to dynamic unbalance. Therefore, using (5),

$$D_I . r_I (m + n) = A_D . a = NE$$

$$\text{or,} \quad D_I = \frac{A_D . a}{r_I (m + n)} = \frac{NE}{r_I (m + n)} \quad . \quad . \quad . \quad . \quad (9)$$

$$\text{and,} \quad D_{II} . r_{II} (m + n) = B_D . b = MF$$

$$\text{or,} \quad D_{II} = \frac{B_D . b}{r_{II} (m + n)} = \frac{MF}{r_{II} (m + n)} \quad . \quad . \quad . \quad . \quad (10)$$

To combine the correction weights S_I and D_I into a single weight W_I in correction plane I and S_{II} and D_{II} into a single weight W_{II} in correction plane II, the construction shown in Figure 8 can be used.

With reference to the balancing of high speed rotors and armatures recent experience has shown that the only safe method to use if reliable results are to be expected is that of balancing the

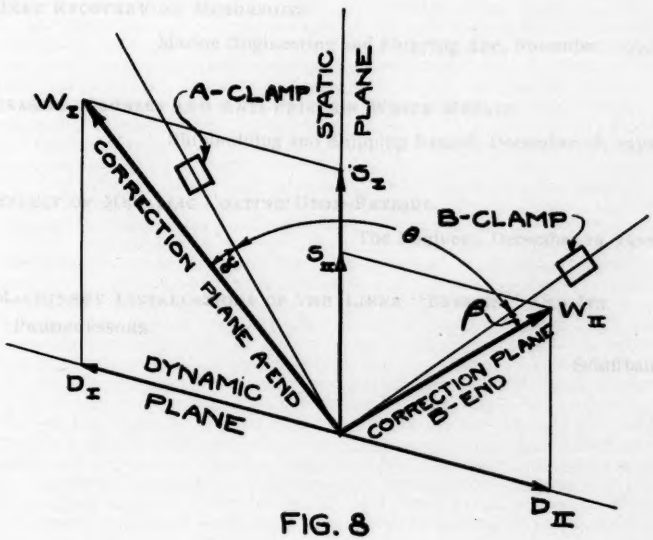

FIG. 8

rotor at its normal running speed. Most balancing machines on the market are designed to balance rotors at a speed usually much lower than the normal running speed. High speed rotors balanced in this manner may be expected in some cases to give trouble due to the possibility of the shifting of windings or slight distortion of the shaft at normal running speed. In this connection, a recent paper "Turbine Vibration and Balancing" (A.S.M.E. paper A.P.M.-51-23) by Thomas C. Rathbone, throws considerable light on this problem and presents a practical method of balancing high speed rotors at normal running speed in their own bearings.

NOTES.

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The Journal of the Institute of Metals, November 1, 1930.

THE EFFECT OF CONTAMINATION BY NITROGEN ON THE STRUCTURE OF ELECTRIC WELDS.
Engineering, October 24, 1930.

HEAT RECOVERY ON MOTORSHIPS.
Marine Engineering and Shipping Age, November, 1930.

BRASSES, BRONZES AND ANTI-FRICTION WHITE METALS.
Shipbuilding and Shipping Record, December 18, 1930.

EFFECT OF METALLIC COATING UPON FATIGUE.
The Engineer, December 19, 1930.

MACHINERY INSTALLATIONS OF THE LINER "BREMEN" AND ITS PREDECESSORS.
Schiffbau.

UNSOUNDNESS IN BRONZE CASTINGS.*

By EDWARD J. DANIELS,† M.Sc., MEMBER.

INTRODUCTION.

The manufacture of sound castings of bronze, particularly the alloy known in Great Britain as Admiralty gun-metal (copper 88, tin 10, zinc 2 per cent), presents some considerable difficulty, and, although many articles dealing with the various aspects of the problem have appeared in the technical press of several countries, the real cause of many unsuccessful castings is still often doubtful.

In the present work an attempt has been made to solve the problem in two ways: (1) by applying existing knowledge to the melting and casting of the alloy, and (2) by examining the effect of various gases on small quantities of the alloy melted in small carbon or fireclay boats in a closed tube.

An extensive examination of the literature on this subject has been made, and the experimental results obtained in the present research have been examined in the light of the information so obtained, leading to a possible explanation of the phenomena observed.

PREVIOUS WORK.

Karr and Rawdon[1] have studied the effect of casting temperature, the character of the mould, and heat-treatment on the physical properties of the alloy. Their main conclusion was that the casting temperature has the greatest effect on the qualities of the casting whatever the type of mould. After studying a large number of castings they concluded that the bronze could be cast within a certain range of temperature, viz. 1120 degrees to 1270 degrees C. (2048 degrees to 2318 degrees F.), and possess satisfactory physical properties. If either extreme of this range were exceeded, the casting would be unsound and would show low strength and elongation in the tensile test. They found that most trouble was caused by the presence of oxide films and pits, which usually occur together with the eutectoid, and so cause great brittleness. Heyn and Bauer[2] have shown that the tin oxide (SnO_2) is insoluble in molten copper-tin alloys and that it is present in the solid either as crystals or as films. Karr and Rawdon found that the average density of their sand-cast specimens was 8.58, and of the chill-cast specimens, 8.6. A fairly high percentage of their test-pieces, even when cast at a temperature within the safety range, gave bad results in the tensile test, and microscopic examination showed the presence of numerous "oxide films" in these specimens.

Carpenter and Elam[3] confirmed the conclusion of Karr and Rawdon, that gun-metal cast above or below a certain range of temperature, 1120 degrees to 1270 degrees C., will be unsound. They also found that however much the metal may have been overheated, if cooled and cast at a temperature within the safety range, it will be sound. They say "the temperature (of casting) is all important, and provided that this can be regulated and controlled, there should be no difficulty about always obtaining sound castings."

Homfray and Adam[4] have discussed the effect of remelting on gun-metal. They say that there is no doubt that virgin metal is the best, and that the zinc should be added as soon as the metal is melted. They discuss the range of pouring temperatures given by different authorities, who give the allowable pouring temperature as varying from 1020 degrees to 1270 degrees C. (1868 degrees to 2318 degrees F.). They say that "from our own experience we are of the opinion that the range of the best casting temperature for

* Presented at the Annual General Meeting, London, March 12, 1930.
† British Non-Ferrous Metals Research Association, Brimingham.

the 88:10:2 is entirely between 1075 degrees and 1175 degrees C. (1967 degrees to 2147 degrees F.), and that castings poured below the former will not be sound, and that separation will be produced in those cast above 1175 degrees C. We are practically with Mr. Rolfe when he refers[6] to 'no falling off till the metal has cooled down to about 1060' (1940), but we should have preferred to give the figure at 1075 (1967)."

F. W. Rowe[6] holds somewhat opposite views to those just quoted. He says that "It is an understood fact that twice melted metal gives much stronger castings than virgin metal. It is a definite rule in the foundry with which the writer is connected never to exceed one-third virgin mix in the gun-metals. Heavy scrap is much better than virgin metal, provided that the composition is correct."

With reference to casting temperature, Rowe remarks that "the primary solidification sets in at 995 degrees C. ± 5 degrees C. (1823 degrees F. ± 9 degrees F.) Ten to twenty pound crucibles are the best, as then the first box need not be cast at such a high temperature to enable the run to be completed. The casting temperature should never exceed 1200 degrees C. (2192 degrees F.) for all normal work, and should preferably be lower. The writer has cast some tons of fairly small light-sectioned castings (½ inch to ⅜ inch) at 1110 degrees to 1140 degrees C. (2030 degrees to 2084 degrees F.) with excellent results. Bars cut from these castings show regularly over 19 tons tensile strength and 18 to 22 per cent elongation."

The effect of rate of solidification on the soundness of bronze has been studied by Sir John Dewrance,[7] who has made a large number of highly instructive experiments, many of which are described in the papers referred to. He indicates the dependence of the correct casting temperature on the type of casting being made, and emphasizes the importance of temperature control to minimize the effects of the gas present in the molten metal. He is in agreement with the views of Genders[8] that control of the gas evolution during solidification will reduce the extent of inverse segregation.

On studying the gas evolved by bronze when heated *in vacuo*, Carpenter and Elam found that a gas of approximately the same composition is present in both sound and unsound castings (both sand and chill). There was not a constant or sufficient difference in the volume of gas obtained from unsound and sound castings to account for the presence of blowholes in the one and their absence from the other. Their final conclusion is that "the most suitable practical way of avoiding porous castings would appear to be to determine the temperature of the alloy so as to ensure that it is poured within the range (1270 degrees to 1120 degrees C.) (2318 degrees to 2048 degrees F.)."

The negative result which these investigators obtained from the determination of the gas contents of sound and unsound metal confirms the results of Guillemin and Delachanal,[9] who found that as much gas was obtained from sound as from unsound metal. However, there is one important point in this connection which seems to have some bearing on the question of unsoundness. All these observers find that sound metal contains much hydrogen with little carbon monoxide and carbon dioxide, whereas unsound metal contains important proportions of the oxides of carbon. This is in direct conflict with the work of Sieverts and Krumbhaar,[10] who find that both carbon monoxide and carbon dioxide are insoluble in molten copper. However, Keizo Iwasé,[11] working with a slightly modified form of apparatus, finds slight solubility of both these gases in solid copper and considerable solubility in the liquid state.

Hampe[12] confirms the observations of Caron[13] that copper, when melted and allowed to cool in a stream of carbon monoxide, gives unsound metal.

On the other hand, Hampe finds that carbon dioxide has neither chemical nor physical action on copper, metal which had been cooled in the gas being perfectly sound.

Thus, the evidence regarding the solubility of the oxides of carbon in pure copper is very conflicting. As regards the solubility of gasses in alloys of copper and tin the amount of information available is very small. Both Sieverts[10] and Iwasé[11] find that the addition of tin to copper lowers its capacity for dissolving hydrogen, and it has already been seen that several observers have extracted oxides of carbon from gun-metal.

The experiments of Röntgen and Schwietzke[30] indicate that sulphur dioxide has no detrimental influence on bronze and may even lead to an increase in strength.

The effect of furnace atmosphere has been discussed by Woyski and Boeck,[14] who lay great stress on correct furnace practice and indicate how spoilt metal may be recovered. They say that "Metal that has been subjected to bad melting practice, whether oxidized or gassed, may be brought back to normal conditions by proper furnace practice. In the case of oxidized metal a deoxidizer or flux is necessary. In the case of gassed metal, a strongly oxidizing furnace atmosphere of a relatively high temperature, so as to produce quick melting, will correct the gassed condition. This has been proved many times. In one case when, on account of a change in the furnace tender, several heats of red brass were gassed, all the castings were returned to the furnace and melted under the conditions just described, the resulting castings were entirely satisfactory, both as to fracture and microscopical characteristics." Again, "The most important cause of gassed metal is the atmosphere of the furnace. With proper regulation of air and fuel, it will not take place in the case of most non-ferrous alloys. It may be contrary to the general opinion, but we believe that an oxidizing condition in the furnace is less troublesome than a reducing, provided that the bath is protected by a thin layer of mineral flux; also that it is more economical in time and fuel. The loss of metal is not appreciably greater. The mineral fluxes protect the surface of the metal and may replace deoxidizers in many cases, but to be certain of the removal of oxides, formed before the metal is melted, the metal must be stirred in order to bring the oxides in contact with the flux." They mention cases where metal which had been gassed in the furnace was remelted under oxidizing conditions and protected by flux, and then gave perfectly sound castings.

Dews[29] considers that melting in an oxidizing atmosphere will lead to improvement in bronze, provided that casting and mould conditions are so arranged as to lead to efficient feeding.

It is improbable that the increased soundness obtained by melting under strongly oxidizing conditions is due to the removal of the soluble gases by direct oxidation, but that that can take place under certain conditions is shown by A. Portevin,[15] who was troubled with unsoundness in gun-metal which was melted in an oil-fired furnace, in which the pressure of air could not be made sufficiently great and the atmosphere of the furnace was reducing. The bronze to be made called for 3 per cent lead, so a suitable quantity of red led was thrown on the surface, stirred in, and the metal cast with the usual precautions. As a result of this treatment the unsoundness disappeared completely. This treatment has been continued for some years, and has proved a complete remedy for the trouble. Portevin also found that many of the patent "dopes" made for obtaining sound castings contain oxide of manganese or some other oxidizing agent.

Slow solidification of the metal in the crucible and remelting before casting has been found by Edwards and Prytherch[16] to improve the density of copper.

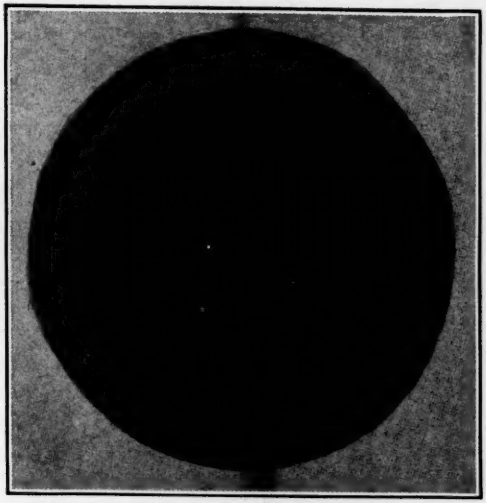

FIG. 6.—× 100.

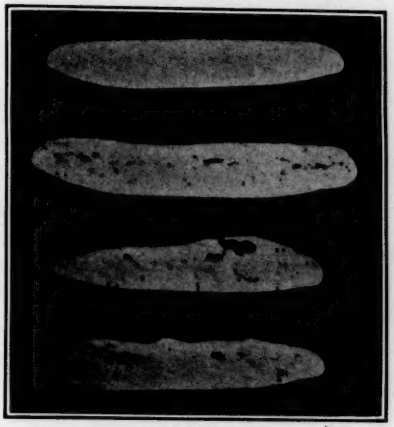

FIG. 7.
Unsoundness in bronze castings.

Archbutt[17] applied this treatment ("presolidification") to an alloy of aluminium with a decided increase in soundness.

A list of further publications dealing with this subject will be found in the bibliography.

PRESENT WORK.

The experiments can be divided into two main groups:

1. The casting of test-pieces from 20 pound melts under various conditions, and the determination of the soundness and strength of the bars.
2. The study of the effect of treatment with pure gases on small quantities of bronze contained in a fireclay "combustion" boat.

The data obtained may be conveniently classed under the following headings:

1. Experimental Method.
2. Simple Melting.
3. "Degasification" with Phosphorus, Manganese, and Nitrogen.
4. Presolidification.
5. Rate of Cooling (Type of Mould and Casting Temperature).
6. Effect of Furnace Atmosphere.

1.—*Experimental Method.* Bronze of the composition 88:10:2 was made by melting together, in Salamander crucibles and under a thick layer of charcoal, virgin metals of high purity. Except in the case of the melts detailed in Table II a coke-fired wind furnace was used. The materials used were:

Electrolytic copper (99.96 per cent Cu) as cathodes.
Electrolytic zinc.
Chempur tin.

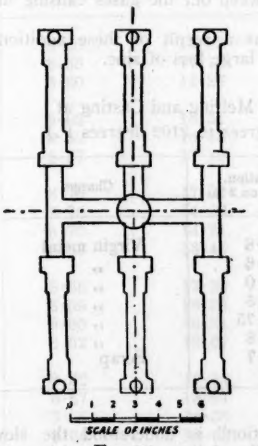

FIG. 1.

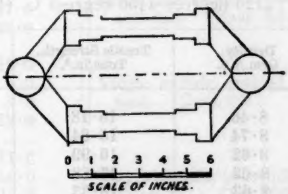

FIG. 2.

The copper was melted first, the zinc added, and then the tin. When the whole charge was well mixed it was withdrawn from the furnace, cooled to the desired casting temperature, and cast into test-pieces, the moulds being

of skin-dried green-sand and formed as shown in Figure 1 for casting six pieces, or as in Figure 2 when only two test-pieces were to be cast at one time. The specimens were allowed to cool in the sand overnight, and after density determinations had been made, they were machined to B.E.S.A. standard 0.25 square inch section and tested for tensile strength and elongation.

For studying the influence of pure gases on bronze the apparatus shown in Figure 3 was used, the metal being melted in a fireclay "combustion" boat and cooled at any desired rate, after gas treatment, either by adjustment of the current in the heating element or by moving the silica tube relative to the heating element.

In all cases temperatures were measured by means of a platinum/platinum-rhodium thermocouple calibrated on a Cambridge portable milli-voltmeter. The casting temperature should be taken as 1120 degrees C. (2048 degrees F.) unless otherwise specified.

The densities of the test-pieces were determined by weighing in air and water at room temperature, giving the density compared with water at 15 degrees C. (59 degrees F.) approximately. The small ingots produced in the boat melts were weighed in air and in water at known temperatures with counterpoised suspension and the density figures corrected to metal at 0 degrees C. and water at 4 degrees C. (point of maximum density).

2.—*Simple Melting.* When the bronze was simply melted and cast, using either virgin or scrap charges, the results shown in Table I were obtained.

3.—*"Degasification" with Phosphorus, Manganese, and Nitrogen.* The opinion is largely held that the addition of small quantities of phosphorus and manganese to copper and its alloys results in increase of soundness. Table II illustrates the results obtained by adding these elements to Admiralty bronze. Table II also shows the effect of passing nitrogen (a neutral gas) through the molten alloy in an attempt to sweep out the gases causing unsoundness.

No striking improvement was obtained as a result of these additions, whilst treatment with nitrogen further led to large loss of zinc.

TABLE I.—Typical Results on Simple Melting and Casting at 1120 degrees–1150 degrees C. (2048 degrees to 2102 degrees F.).

Density. Grm./c.c.	Tensile Strength. Tons/in.².	Elongation. Per cent. on 2 in.	Charge.
8·46	16·18	18·8	Virgin metal
8·74	15·84	11·6	"
8·62	16·99	16·0	"
8·63	17·88	20·5	"
8·63	18·33	16·75	"
8·70	15·53	10·8	"
8·60	17·38	15·7	Scrap

4.—*"Presolidification."* By "presolidification" is understood the slow solidification in the crucible of a metal or alloy followed by remelting and casting in the usual manner. Gun-metal subjected to this treatment has improved tensile properties, but its density remains unchanged, as will be seen from the results obtained, which are collected in Table III.

TABLE II.—Treatment with Phosphorus, Manganese, and Nitrogen. Melting in a Small Town-Gas Injector Furnace.

Density. Grm./c.c.	Tensile Strength. Tons/in.².	Elongation. Per cent. on 2 in.	Treatment.
8·67	17·72	18·5	Virgin metals. 0·04 per cent. phosphorus added to copper when melted
8·58	17·60	18·5	
8·59	16·17	12·0	
8·62	15·06	15·5	
8·62	14·95	8·6	
8·56	17·42	19·5	Scrap metals. 0·04 per cent. phosphorus added before casting
8·57	18·19	24·0	
8·56	15·70	10·0	
8·57	14·26	8·0	
8·56	15·60	12·5	
8·57	17·28	15·0	
8·58	...	...	Virgin metals. 0·05 per cent. manganese added to copper when melted
8·64	...	...	
8·70	18·44	22·0	Nitrogen passed for ½ hr.
8·69	18·54	21·0	
8·69	15·32	10·0	Stand for 20 minutes and cast
8·71	16·69	9·0	

TABLE III.—Effect of Presolidification.

Density. Grm./c.c.	Tensile Strength. Tons/in.².	Elongation. Per cent. on 2 in.	Treatment.
8·60	14·03	7·5	Scrap, melted and cast. (Heat S.)
8·58	17·10	16·0	
8·60	14·28	15·5	
8·63	18·31	24·0	Scrap, presolidified, remelted, and cast. (Heat SA.)
8·59	18·88	27·5	
8·57	17·19	24·0	
8·70	17·09	16·0	Virgin metals, melted and cast. (Heat CD.)
8·70	14·52	8·0	
8·70	14·21	8·0	
8·68	16·48	12·0	
8·65	17·20	11·5	Virgin metals, presolidified. (Heat SC.) Cast 1250° C.
8·59	18·35	16·0	
8·65	16·21	12·0	
8·62	16·67	12·0	
8·62	17·24	15·5	Virgin metals, presolidified. (Heat SD.)
8·67	18·91	18·0	
8·65	18·56	16·5	
8·66	18·62	17·0	
8·64	19·06	26·0	Scrap metal presolidified. (Heat SJ.)
8·64	17·36	19·0	
8·64	17·16	16·0	
8·63	17·92	21·0	

5.—*Rate of Cooling.* In practice the rate of cooling, the casting temperature being constant, depends upon the size and shape of casting being poured, and the character of the mould if of sand or its thickness if a chill mould; if the mould is always the same it will depend upon the casting temperature. The effect of casting temperature with constant mould conditions is shown in Table IV.

The effect of variation in the rate of solidification obtained by casting at constant temperature into metal chill and sand moulds is shown in Table V. The sand mould referred to in column 2 is illustrated in Figure 2, whilst the chill mould was an assayer's button mould, made of copper, casting a button 2.5 inches in diameter.

TABLE IV.—Effect of Casting Temperature.

Density Grm./C. C.	Tensile Strength Tons/in.²	Elongation Per cent on 2 in.	Casting Temperature °C	Casting Temperature °F
8.42	12.08	5.4	1300	2372
8.65	17.11	12.9	1250	2282
8.63	18.33	16.75	1120	2048
8.63	17.88	20.5	1100	2012

TABLE V.—Effect of Chilling.

Metal.	Density. Grm./c.c.	
	Sand-Cast (Green-Sand).	Chill-Cast (Copper Button Mould).
Copper	6·81	8·47
,, ...	7·05	8·10
,, ...	6·94	8·19
,, ...	7·14	8·48
Copper plus 2 per cent. zinc .	8·32 8·28	8·84 8·78
,, ,, 10 ,, tin .	8·11	8·74
Gun-metal, 88 : 10 : 2 . .	8·75	8·77

Thus the size of a casting, its general thickness, and the type of mould, green-sand, dry sand, or metal, will determine the best casting temperature to use.

6.—*Effect of Furnace Atmosphere.* To study the problem, two lines of attack were used:

(1) Melting and solidifying 50-gram charges in a stream of gas, using the apparatus shown in Figure 3.

(2) Melting 10-pound charges in a coke furnace with varying conditions of fire.

A.—Boat Melts.—The method employed was a modification of that used by Hampe in his classical experiments on copper.[12] The weighed sample con-

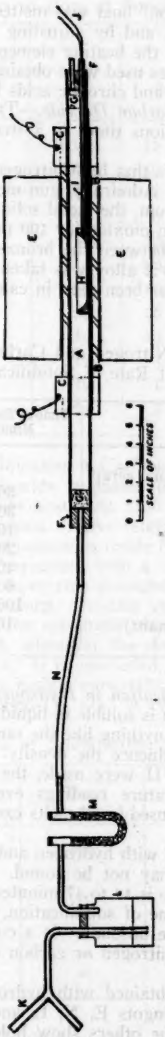

FIG. 3.

tained in a fireclay "combustion" boat was melted in a stream of gas whose effect it was desired to study, and by adjusting the heating current or the position of the boat relative to the heating element the metal could be solidified at varying rates. The gases used were obtained from cylinders and dried by bubbling through sulphuric and chromic acids before entering the furnace.

1. *Effect of Nitrogen and Carbon Dioxide.*—Table VI shows the densities obtained by treatment for various times in a stream of these gases at 1150 degrees C. (2102 degrees F.).

From these results it appears that both nitrogen and carbon dioxide act as neutral gases with respect to Admiralty gun-metal, and that, after all the soluble gases have been swept out, the metal solidified quite sound, even after it had been treated with carbon dioxide for 100 minutes, thus indicating very little, if any, chemical action between the bronze and carbon dioxide. The maximum density of the 88:10:2 alloy was taken from the above to be 8.88, and this is the figure which has been used in calculating the unsoundness of castings.

TABLE VI.—Treatment with Nitrogen and Carbon Dioxide at 1150 degrees C. (2102 degrees F.) Constant Rate of Solidification (approx. 14 minutes).

Mark.	Gas.	Time of Treatment. Minutes.	Density.
VII	Sample of original scrap		8·689
I	Nitrogen	30	8·880
II	,,	30	8·880
IV	Carbon dioxide	10	8·852
V	,, ,,	20	8·881
IX	,, ,,	40	8·878
III	,, ,,	60	8·879
VI	,, ,,	100	8·880
X	Nitrogen (stagnant)	10	8·874

2. *Effect of Rate of Solidification in Hydrogen.*—It was anticipated that, in the case of hydrogen (which is soluble in liquid copper-tin alloys, but probably not in the solid alloys to anything like the same extent), variations in the rate of solidification might influence the density. To test the point the experiments detailed in Table VII were made, the rate of solidification being determined by taking temperature readings every 30 seconds during the cooling. Graphite boats were used in all melts except V, X, and AC, where a fireclay boat was used.

When the metal is saturated with hydrogen and allowed to cool in that gas the resulting ingot may or may not be sound. If the time taken to cool through the solidification range is 14 to 47 minutes (or probably even longer) the ingot is sound. If the time of solidification, however, is between 4 and 1.25 minutes, the ingot is quite unsound. If a correspondingly rapid rate of solidification is employed, in nitrogen or carbon dioxide, the ingots are perfectly sound.

The type of unsoundness obtained with hydrogen is shown in Figure 7, which represents sections of ingots E, N, L, and M. Ingot E is perfectly sound (rate 16 minutes). The others show holes of the same type as are formed in copper which has been rendered unsound by means of hydrogen, but is quite unlike that obtained in commercial casting, in which the holes are generally much smaller.

TABLE VII.—Effect of Rate of Solidification in Hydrogen.

Mark	Time of Treatment at 1150°C. (2102°F) Minutes	Gas	Time of Solidification*	Density
X	20	CO_2	52 sec.	8.88
AC	20	CO_2	57 sec.	8.87
V	20	N_2	1 min. 12 sec.	8.91
AB	20	N_2	0 min. 56 sec	8.87
I	30	H_2	47 min.	8.898
H	30	H_2	30 min.	8.888
G	30	H_2	19 min.	8.893
E	30	H_2	16 min.	8.907
F	30	H_2	14 min.	8.880
N	30	H_2	3 min. 55 sec.	8.19†
L	30	H_2	1 min. 45 sec.	7.95†
M	30	H_2	1 min. 25 sec.	8.04†

3. *Effect of Rate of Solidification in Carbon Monoxide.*—Table VIII shows the results when carbon dioxide is passed through the furnace, the metal being contained in a graphite boat. At 1150 degrees C. the carbon dioxide and the carbon of the boat react to give relatively pure carbon monoxide.

Ingots O and AA showed numerous oxide films on micro-examination, but no blowholes. Further experiments with a 10 per cent copper-tin alloy in carbon boats, using carbon monoxide prepared by the action of sulphuric on formic acid, gave similar results, densities varying from 8.67 to 8.85 being obtained. Examination of the specimens showed that in no case were any blowholes present, but that, whenever the density was low, the metal contained numerous oxide films. It is concluded, therefore, that the low density was due to oxide, and not to carbon monoxide, since when oxygen was absent the ingots were perfectly sound (B, D). A typical oxidized area in specimen

TABLE VIII.—Rate of Solidification in Carbon Monoxide.

Mark.	Time of Treatment. Minutes.	Gas.	Time of Solidification.	Density.
B	10	CO	14 min.	8·887
D	25	,,	14 ,,	8·888
O	20	,,	1 min. 55 sec.	8·72
P	,,	,,	0 ,, 29 ,,	8·64
T	,,	,,	0 ,, 32 ,,	8·77
S	,,	,,	0 ,, 35 ,,	8·74
AA	,,	,,	1 ,, 12 ,,	8·76

* The time of solidification is the time taken for the charge to pass through the freezing range of the alloy (1000 degrees-800 degrees C.) (1832 degrees-1472 degrees F.), as indicated by a pyrometer fastened into the end of the boat close to the metal.

† These figures are probably somewhat high as the blowholes opened on to the surface in many cases, allowing water to penetrate the metal during the final density weighing.

S is shown in Figure 6 at a magnification of 100 diameters. In view of these facts it must be concluded that carbon monoxide acts as a neutral gas towards bronze.

In both copper and bronze hydrogen gas alone is capable of producing unsoundness, which increases with increase in rate of solidification, and which can be avoided entirely by sufficiently slow cooling. Commercial unsoundness, on the other hand, in both copper and bronze is decreased by chilling (see Table V), and at the same time the blowholes are generally quite small and spherical, whereas the cavities produced by pure hydrogen in bronze (Figure 7) and in copper* are large and irregular in shape.

The type of unsoundness occurring in commercial copper has been reproduced by Allen by casting copper containing small quantities of oxygen and hydrogen. The quantity of hydrogen necessary to give this effect was found to be quite minute and could not be removed by inert gases, although, if oxygen were absent, treatment with inert gases before casting enabled sound ingots to be obtained.

Allen found that carbon monoxide was a suitable inert gas for copper, and experiments have shown that it is also inert to bronze. He obtained a typically practical unsound casting of pure copper by treating cathode copper with carbon monoxide at 1150 degrees C. (2102 degrees F.) for one hour and then casting (in the same atmosphere) into a warm steel mould, the copper entering the mould through a silica tube lined with copper oxide, which was picked up by the metal in its passage along the tube. If the tube were clean and no oxidation of the metal occurred, the casting was perfectly sound.

Bearing in mind the similarity of results obtained with copper and bronze, detailed above, it was not unreasonable to suppose that a similar state of affairs might exist with bronze. Accordingly this experiment was repeated in Allen's furnace with a bronze containing 10 per cent tin. No zinc was added as contamination of the furnace was undesirable. The ingot produced had a density of 8.28 and showed small globular blowholes and oxide streaks. The unsoundness of this casting was typical of that found in practice, and it suggested that the presence of both hydrogen and oxygen in molten bronze may be the factor which determines the production of unsoundness in practice. This seems to offer an explanation of the following results obtained by melting in varying furnace atmospheres and casting into sand moulds.

B.—*Furnace Melts.*—In these experiments, designed to study the effect of varying furnace conditions on the soundness of cast bronze, 20-pound charges were melted in two distinct types of fire. First, a "reducing fire" in which the furnace hole was kept full of coke and the damper opened just enough to draw the products of combustion into the flue. Second, an "oxidizing fire" in which the fuel bed was kept as thin as possible and the damper maintained full open, so that there was excess air passing through the fire (Bamford and Ballard[20] have found over 1 per cent of hydrogen in the furnace atmosphere 10 minutes after re-stoking.)

In order to determine the unsoundness of the castings the specific gravity was determined by the method of Archimedes and corrected (reducing the figures 0.02 compared with previous ones) for temperatures of determination and then the percentage of voids calculated, using the following figures for the maximum density of the various alloys:

Density of perfectly sound copper	8.942
Density of perfectly sound copper-zinc (2 per cent Zn)	8.92
Density of perfectly sound copper-tin (10 per cent Sn)	8.90
Density of perfectly sound copper-tin-zinc (88:10:2)	8.88

* N. P. Allen, "Experiments on the Influence of Gases on the Soundness of Copper Ingots"; also Edwards and Prytherch.

The first two of the above figures are due to Norbury,[13] and the last two were obtained from the melts in carbon dioxide and nitrogen described above.

Table IX shows the results obtained for soundness and strength of the 88:10:2 alloy melted under the conditions indicated and cast in skin-dried green-sand moulds (as in Figure 2).

These results indicate that the furnace conditions during melting of the alloy can be adjusted to give castings with a high degree of soundness or *vice versa* (KJ, density, 8.5; KL2, density, 8.77), and at the same time the "oxidizing" condition does not lead to low results in the tensile test (*cf.* KF2, 19.71 tons and 28.5 per cent elongation). At the same time, better results were obtained by simple melting in an oxidizing atmosphere than by presolidification of the metal in a partially oxidizing atmosphere, although compared with simple melting in a partially oxidizing atmosphere, presolidification has resulted in increased soundness.

TABLE IX.—Effect of Furnace Atmosphere (Casting Temperature of all Specimens, 1150 degrees C., 2102 degrees F.).

Mark.	Density. Grm./c.c.	Percentage Unsound.	Tensile Strength. Tons/in.².	Elongation. Per cent. on 2 in.	Fire Condition.
KC2	8·110	8·9 (Cu 90) (Sn 10)	...	...	Reducing
KF2	8·751	1·45	19·71	28·5	Oxidizing
KJ1	8·507	4·20	15·35	20·0	Partially oxidizing
KJ2	8·501	4·27	16·35	20·0	
KK1	8·669	2·04	18·14	20·0	Partially oxidizing
KK2	8·739	1·62	16·24	13·0	Half previous charge presolidified
KL1	8·748	1·49	...	...	Oxidizing
KL2	8·771	1·23	...	...	"

The influence of this change in fire conditions on pure copper was found to be negligible (see Table X), which also shows that the addition of tin to zinc does not render copper perfectly sound, *i.e.* does not remove Cu_2O completely.

It is reasonable to expect that Allen's theory that unsoundness in copper is due to the reaction between oxygen and hydrogen (which he has supported with considerable experimental data) can be extended to cover the case of bronze. The fact that copper and bronze do not behave in a similar way with respect to variations in furnace atmosphere renders a modification of Allen's theory necessary before it can apply to bronze. The theory developed by Allen is based on the formation of steam from hydrogen and copper oxide absorbed in molten copper.

$$H_2 + Cu_2O \rightleftarrows H_2O + 2Cu \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In bronze, however, the Cu_2O is in equilibrium with tin and zinc according to the equations (2) and (3).

$$2\,Cu_2O + Sn \rightleftarrows SnO_2 + 4Cu \quad . \quad . \quad . \quad . \quad (2)$$

$$Cu_2O + Zn \rightleftarrows ZnO + 2Cu \quad . \quad . \quad . \quad . \quad (3)$$

TABLE X.—Effect of Additions to Copper.

Mark.	Composition.			Sand-Casting.		Chill-Casting.		Fire.
	Copper. %	Tin. %	Zinc. %	Density.	Percentage Unsound.	Density.	Percentage Unsound.	
KA1	100	...	...	6·810	23·8	8·465	5·3	Reducing
KC1	100	...	...	7·052	21·1	8·101	9·4	,,
KD1	100	...	...	6·939	22·4	8·192	8·4	Oxidizing
KF1	100	...	...	7·142	20·1	8·476	5·2	,,
KLA	100	...	...	7·318	18·1	...	...	,,
KA2	98	...	2	8·324	6·7	8·836	0·95	...
KD2	98	...	2	8·238	7·1	8·784	1·5	...
KC2	90	10	0	8·110	8·9	8·767	1·8	...

But SnO_2 is assumed to be practically insoluble in molten bronze (2), and so is ZnO. If these assumptions are allowed, it will follow that their active masses in the liquid metal are constant. And, since copper, tin, and zinc are constant, Cu_2O should theoretically be constant and independent of furnace atmosphere.

The relationship between the Cu_2O and H_2 in equilibrium in molten copper at a constant temperature is shown in Figure 4 (after Allen) when the atmosphere surrounding the metal is constant (this follows from the Distrtibution Law). If the quantity of water vapor in the furnace atmosphere is low the curve will assume a position such as O in Figure 5, and will be displaced to, say, position R (Figure 5) if the atmosphere is high in water vapor. These two curves, O and R, can be assumed to represent the conditions with a thin coke fuel bed (O) and a very thick fuel bed (R), since coke often contains appreciable quantities of moisture.

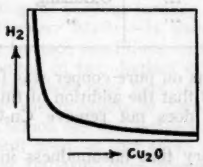

FIG. 4.

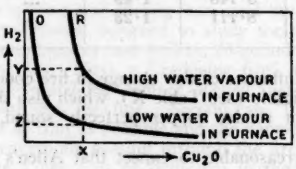

FIG. 5.

But the assumptions made with regard to bronze fix the Cu_2O independently of variation in atmosphere. Let the quantity be represented by X in Figure 5. Then with the two atmospheric conditions under discussion, the quantity of hydrogen in equilibrium in the molten bronze will be Y for "reducing fire" and Z for "oxidizing fire"; in other words, there is more hydrogen to form water vapor in case R than in case O, and therefore an "oxidizing" fire will give less unsound metal than a "reducing" fire. At the same time there is possibly free hydrogen in the atmosphere of the reducing fire which would tend to increase this effect.

It is possible that an explanation of the behavior of bronze on melting and casting in the foundry will be found along some such lines.

CONCLUSIONS.

1. The observations of Karr and Rawdon, and Carpenter and Elam, with regard to the relationship between casting temperature and unsoundness of bronze have been confirmed.
2. Variations in casting temperature affect the rate of solidification, other conditions remaining constant, and similar variations in rate of solidification obtained by constant casting temperature into moulds of different materials also affect the density of the castings in the same way.
3. Nitrogen, carbon dioxide, and carbon monoxide have been found to be neutral towards bronze.
4. Hydrogen is capable of causing unsoundness in bronze at certain rates of solidification, and this unsoundness can be suppressed by treatment with neutral gases.
5. It is possible that normally occurring unsoundness is due to the combined presence of hydrogen and oxygen in the molten bronze. It is different in character from that produced by hydrogen alone.
6. Improvement in density of sand-castings can be obtained by melting in a pot furnace with a thin fuel bed and good draught, compared with melting in a very thick fuel bed and poor draught. This is not so with pure copper to anything like the same extent.
7. Degasification with nitrogen, deoxidizers, and presolidification gave negative results as far as improvement in density was concerned, but presolidification seems to increase the strength of the metal.

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THE EFFECT OF CONTAMINATION BY NITROGEN ON THE STRUCTURE OF ELECTRIC WELDS.*

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From time to time suggestions are made that the needles found in welds are caused by oxygen, and that they are not produced by nitrogen. This point was therefore specially studied during the course of a general investigation which is being made on welding. At a stage where it had been found definitely that nitrogen caused needles in welds and that, in a weld made in oxygen, they were neither present nor could they be made to appear, startling evidence was put forward by Alexander in America in support of the contention that oxygen was the only cause of needles. In view of this it was felt that the investigation should be extended to ascertain whether the former conclusion was in error or not. As no work appears to have been published hitherto on the effect of contamination from the atmosphere on weld metal, and a knowledge of this is essential for the interpretation of the structures found in specially prepared welds, the present paper gives the result of those portions of the investigation dealing with atmospheric contamination and with the structure of welds made in different gases. The variation of structure according to the type of electrode used and the results of mechanical tests are described in the official reports of the investigation.†

* Paper presented before the Iron and Steel Institute, Prague meeting, Czechoslovakia, September 15 and 16, 1930. Abridged.

† Technical Reports for 1928 and 1929 of the British Engine, Boiler and Electrical Insurance Company.

The work described is the result of the private enterprise of the author's company, who had no direct interest in the result of the research. Under these circumstances there is limitations to the facilities available, and the extent of the work was not as comprehensive as it might have been if carried out in a laboratory specially fitted out for welding research. Similarly, analyses were made only when the author considered that the evidence was insufficiently strong for conclusions to be drawn with absolute confidence. Where definite carbon contents are given the determinations were made by combustion.

Part I.—The effect of Contamination by Nitrogen.—In this section are described some of the structures that are found or that can be induced in welds. They have been largely exemplified by means of a special bar of welded Armco iron which was used as a standard of comparison. The bar was first thoroughly explored microscopically and found to be free from visible carbon. A slice was cut from the outside and cut into strips, 4 to 5 inches long, which were used as bare-wire electrodes. By the use of these, two pads of metal were deposited by the metallic arc on to the sawn surface of the bar, the current being taken from a continuous-current generator and the two pads respectively deposited with changed polarity. The weld made with the electrode negative was sent for examination to Loughborough College, where all other analyses for nitrogen were made, no particulars of the source or the microstructure of the specimen being given. It was found to contain 0.228 per cent of nitrogen, a high figure.

In a carbonless weld or one that is not contaminated, the structure consists of polyhedral grains of ferrite. Where the lower runs of weld metal have been normalized, or partially normalized, intermediate structures may be found; the structure to be described in this section, therefore, applies mainly to the top run of weld metal. As it is usual for an electric weld either to contain a certain amount of carbon or to be contaminated by the atmosphere, in addition to the ferrite there is generally present a dark body which, at high magnification, is found to be made up of a constituent that is largely cementitic. This assumes a long-axed shape when the ferrite grains are columnar, but portions segregate to the boundaries of the ferrite grains.

As the most striking way of showing that a body resembling pearlite can be introduced into welds by atmospheric contamination was to normalize a carbonless weld, a normalizing treatment was carried out on the weld made with Armco iron. In the microphotograph, the parent metal was seen to be free from carbon, a large number of small and a few larger oxides only being visible. In contrast to this, the weld metal contained a considerable amount of a dark substance, resembling pearlite. In between the two structures, the ferrite was full of a large number of needles. The similarity between this transformed structure of the Armco iron and that of Armco iron into which sufficient nitrogen has been introduced is most marked.

As the dark body and also the needles do not come from the rod, the only possible source is the atmosphere. The only constituents of the atmosphere present in sufficient quantity to change the microstructure appreciably are oxygen and nitrogen. Several researches have been carried out in which oxygen has been introduced into iron and steel without the features of the micrograph being reproduced; it is only reasonable, therefore, to conclude that they are caused by a combination of iron and nitrogen, or, when carbon is present, of both these substances together with carbon. On the other hand, where nitrogen has been introduced into steel, structures have been induced similar to those shown in the micrograph. The latter, therefore, affords very strong evidence that the needles are set up by nitrogen, and this is confirmed by the complete similarity of contaminated welds to nitrogenized Armco iron, after each of various forms of heat treatment, and by the exam-

ination of welds made in nitrogen that have been given similar forms of heat treatment. The dark body resembling pearlite is, therefore, none other than braunite, a nitrogenous compound resembling pearlite, and the absence of needles is due to the large quantity of nitrogen present. Had the weld been heated at a suitable temperature in hydrogen with the object of partially eliminating the nitrogen, the braunite would without doubt have been replaced by needles.

In illustration of the fact that the structure is by no means exceptional, Figure 6 is shown, which represents a weld made with a Swedish-iron bare-wire electrode. The carbon content was only 0.02 per cent, and, as is to be seen, the weld contains a large amount of braunite. Some needles are present.

Quenching mild steel from 580 degrees C. has no, or no appreciable, effect on the structure. With welds made in nitrogen, or ordinary welds contaminated by the atmosphere, the opposite obtains. Nitrogen depresses the lower critical temperature, and the pearlite constituent enters into solution, and when a small specimen is quenched reappears in the form of a bright body. This does not darken with alkaline sodium picrate and is evidently a nitrogenous austenite rendered stable by the nitrogen content. Sometimes this body is partially or entirely martensitic. The needles enter into solution as a result of this treatment, but reappear if the specimen is reheated and slowly cooled.

When what is intended to be a normalizing treatment is carried out too hurriedly on small specimens of contaminated welds—say, when an Izod test-piece is cooled in the air—it has sometimes been noticed that the central portions of what should be pearlitic areas are bright, giving the impression that the pearlitic constituent is largely dissociated into cementite. The cause of this had hitherto been obscure, and the bright body had been assumed to be cementitic, but the experiments made on welds containing braunite led to the suspicion that this body, strange as it may seem, was largely austenitic. Again, it had for some time past been noticed with ordinary contaminated welds that, if the treatment had been carried out too rapidly, instead of needles being formed, as would have happened with a normal rate of cooling, a white constituent was present as islands among the ferrite grains.

An Izod test-piece of a weld, which had been made with a Swedish-iron electrode and afterwards heated to 910 degrees C. and cooled in the air, was found to have the structure described. The weld contained only 0.02 per cent of carbon and showed a large number of bright islands edged with a dark constituent resembling troostite, as shown in Figure 13. To confirm the identity of the white constituent, a specimen of this weld was first etched in boiling alkaline sodium picrate, when the interior of the grains in question remained uncolored, indicating that they were not cementitic; at the same time, the outer edges etched up dark as before. Next, the weld was given a tempering treatment at 580 degrees C. for five minutes, followed by a comparatively slow rate of cooling. As a result, what were suspected to be austenitic grains broke down into braunite, and the outer edging that was originally black broke down into the cementitic form. This distinctly confirms that the original grains were similar to austenite at the interior. The weld contained 0.228 per cent of nitrogen.

To confirm the cause for this change in structure, a small portion of the bar of nitrogenized Armco iron supplied by Dr. Bramley was first heated to 910 degrees C. and allowed to cool rapidly in air, when austenitic grains edged with what appeared to be troostite were formed, the appearance being similar to that found in contaminated welds. The sample was next tempered at 580 degrees C. in the same manner as the Armco-iron weld, after which it was allowed to cool slowly. This resulted in a structure exactly the same as that of the weld, the austenitic being turned into pearlitic grains, which were

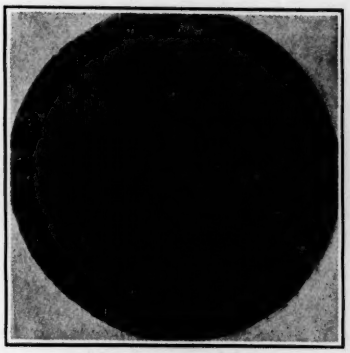


FIG. 6. NORMALIZED WELD. × 250.

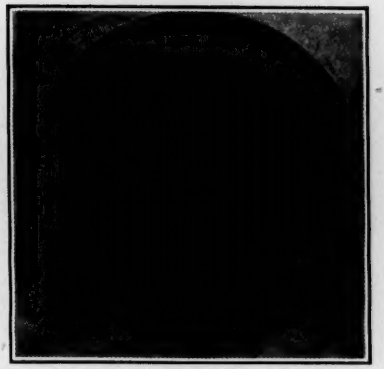


FIG. 13. WELD RAPIDLY AIR-COOLED FROM 910 DEGREES C. × 1000.

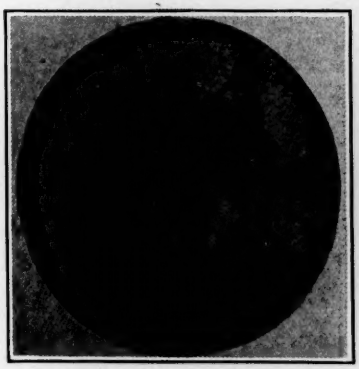


FIG. 22. NORMALIZED WELD MADE IN NITROGEN. × 900.

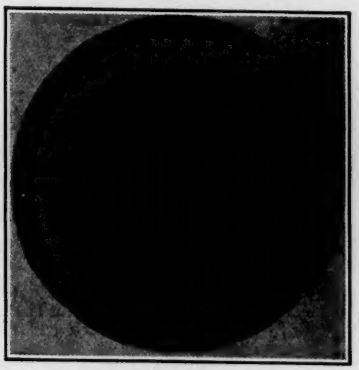


FIG. 23. PARTIALLY DENITROGENIZED AND DECARBURIZED WELD. × 300.

(Microphotographs Reduced to Three-quarters Full Size in Reproduction.)

cementitic at the boundaries. Nitrogen is undoubtedly the cause of the apparently high carbon content of welds made with bare-wire electrodes or electrodes of which the covering shuts out the atmosphere inefficiently.

Part II.—Welds made in Various Gases.—In order to confirm the cause of the structures described in Part I and to account for the presence of needles in welds, a large number of specially prepared welds were made. These welds were made in the laboratory of the Quasi-Arc Company, and to this company the author's best thanks are due for the infinite trouble they took in laying the deposits again and again. The apparatus, in its final form, consisted of a metal box of which the top was for the most part covered with a glass, made air-tight with plasticine, for observation purposes. At the top was also an inlet connection from the gas cylinder and a rubber gland through which the electrode worked. At this side was a manometer for registering the air pressure, and at the bottom a cock for the outflow of gas and for letting out water. The plate on to which the weld metal was deposited was tack-welded to a heavy plate at the bottom of the box, to give rigidity. A flow of gas was maintained during the period of welding, the outlet being led to a deep tank, where it was water-sealed and the gas allowed to bubble through the water. With the exception of the one weld made in oxygen, the apparatus was filled with water, which was then displaced by the particular gas used, to prevent air being entrapped. Though it was realized that the presence of moisture within the box might affect the validity of the experiments, experience showed that the result was not affected by any gas into which the water was dissociated.

Series 1.—For this series, an 8 S.W.G. bare-wire electrode, made of mild steel containing 0.12 per cent of carbon, was used. It was connected to the negative pole of the generator and a pressure of 60 volts was applied, the welding current being 150 amperes.

Welds made in Nitrogen.—The weld metal, as received, when unetched contained very little non-metallic matter. An etched specimen showed a well-marked Widmanstätten structure. At a high magnification it was seen that the pearlitic constituent was mainly in the form of long-axed grains, a portion forming a coating at the grain boundaries. When normalized in a furnace at 910 degrees C., the grain-size was refined, and at parts of the weld the pearlitic constituent was thrown out to the grain boundaries. Elsewhere this body was present in well-formed grains (Figure 22). There was an entire absence of needles. This might without consideration be construed as furnishing proof that needles in welds are not caused by nitrogen. It is to be recollected, however, from the result of the research by Bramley and Haywood, carried out on steels containing nitrogen, that, with a steel free from carbon, the nitrogen content, when low, appears in the form of needles, but when high it forms braunite. Here, as the weld had been made in the absence of oxygen to burn out the carbon, it was only to be expected that the weld metal would contain more carbon than a weld made in air with a similar electrode, and there was therefore less likelihood that needles would be present.

Following on this reasoning, it was concluded that, if a treatment were devised that would only have the effect of reducing the quantity of nitrogen or carbon, and not of introducing any other element that could form needles, then, if nitrogen were a cause of needles in welds—a matter which has been disputed—needles would appear at parts where the treatment had been sufficiently drastic, but not too severe. The most suitable method that suggested itself was to heat the weld in hydrogen at a temperature that would tend to drive off nitrogen if present in the weld, the heat being applied for a period insufficient for the whole to be driven off. Hydrogen was deemed to

be all the more suitable, as any reduction of carbon that it effected would allow the nitrogen to form needles more readily. At the same time, it was necessary for the treatment to be carried out in an atmosphere that could not possibly, by itself, have the effect of introducing needles to a weld. As hydrogen had never been known to set up needles, it seemed to be a pre-eminently suitable means for shutting out the atmosphere or any gas that could vitiate the value of the experiment.

The experiment was carried out with a specimen as received. At the conclusion, the surface was found to be decarburized and deeply etched; it showed a beautiful scintillating ferritic structure, free from other constituents. The top outer surface was removed with emery paper, and afterwards re-polished and etched with acid. Examination showed that the structure consisted of a mass of needles, exactly similar to those found in the bottom runs of low-carbon welds made in the atmosphere, or in contaminated welds that had been heat-treated at a sufficiently high temperature. The new structure is shown in Figure 23, which is from the same part of the specimen as that shown in Figure 22.

The specimen was next cut perpendicularly to the polished surface, to allow of examination from the surface inwards. The result was exactly what had been conjectured from theoretical reasoning, prior to the inauguration of the experiments. At the inner part of the specimen, the structure had been normalized, but the nitro-pearlitic constituent did not run round the grain boundaries so much as in the specimen normalized in air, owing to the fact that the latter specimen had been normalized at an unnecessarily high temperature. There was a gradual transformation from braunite at the interior to a needle structure at parts nearer the outside of the specimen.

At a later stage, another specimen, as received, was heated to 900 degrees C. for half an hour in a furnace to which air was freely admitted, to ascertain if any change in structure could be caused by contact with the oxygen of the air. No needles were induced. The experiment was repeated at the same temperature for 1½ hours, resulting in the decarburization of the outer skin of metal. The specimen was then cut so that an examination could be made from the decarburized surface inwards. Again, no needles were induced by the oxygen, and the nitrogen in the weld was unable to form needles, owing to its having been driven off at a quicker rate than the carbon. It was thus shown that a weld made in nitrogen from which all other gases had been excluded, and made with bare wire so that it might be entirely free from possible adulteration from fluxes used on the electrode, contained all the necessary constituents for producing the needles so commonly found in welds made in the atmosphere.

Welds made in Oxygen.—Before the weld just mentioned was deposited, a weld had been made in oxygen. It had the usual weld Widmanstätten structure, which broke up into needles when normalized. As this behavior, judged by several researches made on the effect of oxygen on steel, did not seem normal, it was felt that all the original air had not been eliminated from the chamber before the weld was made. The experiment was, therefore, repeated with the apparatus arranged as described, the chamber being first flooded with water, and a gauge-glass fitted. The pressure did not fall below 2 inches of water-gauge. Great difficulty was experienced in laying down the metal, owing to the sticking of the electrode. The difference between the new and the old result is worthy of note.

The sample, as received, consisted of a bead of weld metal on to which a small run was laid with the arc unbroken. The metal was generally clean, but it contained numerous small particles of oxide. The lower bead consisted of polyhedral grains of ferrite, which contained a small amount of

pearlite at the grain boundaries. The top run consisted of the usual Widmanstätten structure. No needles were present, and, as shown in the next paragraph, no needles were induced by heat treatment. There was a film, probably oxide, locally at the boundaries of the grains throughout the weld.

A well-distrtibuted uniform pearlitic structure was set up by a normalizing treatment at 910 degrees C. in a furnace. The carbon content of the welding rod was not oxidized, and, in fact, the carbon content of the weld appears to be very similar, namely, 0.12 per cent. The weld was devoid of needles throughout.

In order to illustrate forcibly the differences between this weld and that made in nitrogen, the weld made in oxygen was heat-treated in hydrogen, similarly to the other. The heat treatment was carried out independently, in order to avoid any suggestion that gas had passed from one weld to the other. The normalized sample was used. At the conclusion, the surface, which had been deeply etched by the hydrogen, was examined, when it showed a ferritic structure, free from other constituents, as before. The interior of the specimen was unaltered.

Later, as a higher temperature had been adopted for the experiments made in America, it was felt that the experiment would be more convincing if repeated at the temperature adopted there; otherwise it might be imputed that the absence of needles was due to the specimen having been heated at an insufficient temperature. The treated specimen was, therefore, heated at 900 degrees C. for half an hour in a furnace to which air was freely admitted. No needles were induced at any part of the structure.

Series 2.—After the first series tests had been completed, the evidence mentioned in the first paragraph of the present paper was put forward in America, where needles in welds were ascribed only to oxygen. It was, therefore, considered desirable to repeat and extend the experiments. The original program was arranged for welds to be made in several gases with (1) a 6 S.W.G. electrode composed of a good quality Swedish charcoal iron, and (2) an 8 S.W.G. electrode made of a mild steel containing 0.12 per cent of carbon, as before. The current conditions were the same as for the previous series, but with the thicker Swedish iron, a current of 200 amperes was used.

Welds made in Nitrogen.—During the welding operation thick black fumes of an iron nitride collected and condensed on the inner walls of the box. A sample weld, made using a Swedish-iron electrode, heat-treated for a quarter of an hour in a furnace and normalized, showed the presence of a pearlitic constituent and of large and small needles. Clearly, the needles, as well as the pearlitic constituent, were caused by nitrogen. A sample weld, made using a mild-steel electrode, in the condition as received, contained very little non-metallic matter, and showed a miniature Widmanstätten structure, similar to that shown by the last weld. A sample, heat-treated for a quarter of an hour in a furnace and normalized, showed the presence of a pearlitic constituent and of large and small needles.

Welds made in Carbon Dioxide.—These were particularly included on account of the prevalence of needles in welds made by the carbon arc. No fumes were developed. Using a Swedish-iron electrode, the sample as received contained numerous oxides. The structure consisted of polyhedral grains of ferrite. No pearlite was visible, as there was no carbon, or gas capable of forming a pearlitic constituent, present. There was no sign of needles. A sample heated for a quarter of an hour in a furnace and normalized was inappreciably altered, no needles being present. Using a mild-steel electrode, the sample, as received, contained numerous oxides. The structure consisted of polyhedral grains of ferrite, no pearlite being visible.

There was no sign of needles. A sample heated for a quarter of an hour in a furnace and normalized was inappreciably altered, except that traces of cementite were found at the grain boundaries. Needles were again absent.

Welds made in Oxygen.—During the welding operation red fumes rose within the box; they consisted of an iron oxide. A large amount of oxide deposit was found within the box. Using a Swedish-iron electrode, the sample as received contained numerous oxides. The structure consisted of polyhedral grains of ferrite, no pearlite being visible. There was no sign of needles. A sample heated for a quarter of an hour in a furnace and normalized was inappreciably altered. The absence of needles was demonstrated by examination under the microscope. Particular emphasis is laid on the fact that the absence of needles, both here and in the welds made in carbon dioxide, is in agreement with what was to be expected from the "as-received" structure. It has been found throughout the experiments that needles are formed only when "as-received" specimens show the constituent described, in addition to pure ferrite. Equally, in every weld examined that has shown a Widmanstätten structure before heat treatment and needles after heat treatment in an ordinary furnace, whether it had been made specially in nitrogen or according to usual practice in air, a similar needle structure has been produced by a correctly regulated heat treatment in hydrogen.

Up to this stage, the results showed that welds made in nitrogen, using both electrodes, contained needles, but that when they had been made in CO_2, a gas containing oxygen, no needles were formed. Equally, the welds of Series 1, made in oxygen with a Swedish iron and a mild-steel rod, were both devoid of needles. It therefore appeared to be definitely proved that nitrogen alone was capable of forming needles. It was decided, however, that to make this series complete a repeat weld should be made in oxygen with a mild-steel rod.

During a first attempt to weld in oxygen with mild steel, the collar at the top of the box through which the welding rod slid cracked, and, in spite of the precautions taken to maintain a positive pressure, the result led to the inference that air had leaked into the box. The weld, though free from needles when "as received," showed their presence when normalized. The collar was removed and a repeat test made. The same result was obtained. As there was no obvious reason why needles should have been formed when they were entirely absent in the specimen of Series 1 made under identical conditions, and in the weld made with a Swedish-iron electrode, it seemed clear that some agent, not there before, had been present. As nitrogen was the most obvious agent to suspect, and the weld was of sufficient size for the purpose, Dr. Bramley was asked to make an analysis for this gas. The weld was found to contain 0.079 per cent of nitrogen.

In order that the significance of this figure may be gauged it should be mentioned that needles are formed in Armco iron having a nitrogen content of 0.015 per cent and over, and that, with nitrogen introduced into ordinary steel, needles are formed locally when the average nitrogen content is as low as 0.01 per cent. This shows the ease with which nitrogen produces needles, and the analyses made clear that the present sample gave no evidence whatsoever that oxygen could cause needles.

Welds Made in Pure Oxygen.—Before the inauguration of the experiments it had appeared, from the information given by the makers, that the oxygen used was sufficiently pure for the experiments. At this stage of the investigation, in view of the erratic results, further inquiries were made, when the makers admitted that the oxygen perhaps contained a little nitrogen. Fresh samples were therefore made with electrolytic oxygen guaranteed to

have a purity of 99.5 per cent. For this purpose, it seemed that no object would be gained by repeating the weld with Swedish iron, in which there had been a complete absence of needles.

Using a mild-steel electrode, the sample as received consisted of polyhedral grains. There was no vestige of a Widmanstätten structure. A sample heat-treated for a quarter of an hour in a furnace and normalized was inappreciably altered. There was no sign of needles or pearlite, but there were numerous small oxides and the metal was considerably burned locally.

In view of the difficulties experienced during the course of this investigation, it is easy to realize how the results obtained by different experimenters have been so inconsistent. It would seem from the experiments that, when welds are being made in oxygen, the leakage of only a small quantity of air will affect the result, and in this connection it should be remembered that, as air contains four times as much nitrogen as oxygen, the presence of a trace of air is of serious moment.

General Comment on Results.—In every instance where normalized samples showed needles, as-received samples, if not already containing needles, showed what approached a Widmanstätten structure, which was evidently the source of the needles. This structure was the same whether carbon was present or absent, and with normalized specimens was sometimes entirely replaced by needles, no trace of pearlite or braunite being visible—a statement which applies equally to all welds made in air or gases examined during the course of the investigation. Of all the welds made with a special electrode, consisting of an 8 S.W.G. welding wire from which dissolved gases had been removed by a treatment in hydrogen at 1000 degrees C., and the Swedish-iron electrode, the welds made in nitrogen alone, when normalized, showed a pearlitic constituent. This undoubtedly was a nitrogenous body, and one capable of being broken up into needles when reduced by hydrogen.

It would be difficult to reconcile all the facts with the idea that oxygen is the source of any needles found, and this could only hold if oxygen were able to combine with iron and form a eutectoid similar to pearlite, capable of entering into solution at a temperature below 900 degrees C. In considering the possibility of oxygen being the source of needles in welds it must be remembered that, although considerable research has been carried out on the introduction of oxygen into steel, no authentic record can be traced that needles have been formed as a result.—"Engineering," Oct. 24, 1930.

HEAT RECOVERY ON MOTORSHIPS.

During the past few years, shipowners who have decided to adopt Diesel propulsion have urged engine builders to concentrate more and more on increasing still further the economies of internal combustion engined vessels, since it is natural that attention should have been drawn to the comparatively large amount of heat that is normally wasted in exhaust gases, when they are discharged to the funnel.

Three or four years ago, some tentative efforts were made to retain a certain proportion of this heat, but it was not considered that the construction of exhaust-gas boilers for the purpose involved any special features. The result was that the degree of economy was unsatisfactory and the boilers did not stand up to the work. It was, therefore, not until two or three years ago, when specially designed exhaust-gas boilers were introduced, that any real interest was taken in the possibilities of their installation both in cargo and passenger vessels.

Since that time progress has been so rapid that probably about half the oil-engined ships of big tonnage now under construction will be provided with waste-heat boilers. Recently, the majority of big liners, placed in commission, has been so equipped. In some cases, as for instance, on a large motor liner like the *Britannic*, where much steam is needed, the economy that can be effected is considerable. It is estimated that on this ship the steam raised from the exhaust-gas boiler installation would have required the burning of 4 tons of oil daily had oil-fired boilers been installed for the purpose.

The capital cost involved is practically no more than with normal oil-fired boilers, since the exhaust-gas boilers act also as silencers in most cases. Not only that but, with a suitable slight alteration in design, they can be combined with spark arresters, which is an important feature on some tankers, owing to certain regulations regarding oil-engine driven tankers entering German harbors.

While it may be agreed that the utilization of the exhaust gases from Diesel machinery for raising steam might be worth while, when four-stroke engines are employed, on account of the relatively high temperature, it was until recently the general opinion that the temperature of the exhaust in a two-stroke plant was too low to warrant passing it through a boiler. This belief is, however, no longer held and many of the recently constructed two-stroke engined ships both small and large, cargo and passenger, are provided with waste-heat boilers. Roughly speaking, it is estimated that the average exhaust-gas boiler installation adds about 5 per cent to the overall efficiency of the machinery, when full consideration is taken of capital and other costs.

The amount of steam that can be raised from four-stroke Diesel machinery, with a normal exhaust temperature of, say, 800 to 850 degrees F., is approximately 1 pound per brake horsepower at a pressure of 100 pounds per square inch. This amount could be increased by utilizing the jacket water for steam heating, but it is generally desirable to take a conservative view in estimating the amount of steam to be generated. With two-stroke engines having an exhaust temperature of 700 degrees F., and allowing for a temperature drop of 300 degrees F. (namely from 700 to 400 degrees), the amount raised is usually about 0.9 pound per brake horsepower hour.

In the case of a recent test on the motor cargo ship *Sheaf Holme*, equipped with a 1500-brake horsepower Doxford two-stroke engine, it was found that the boiler, of the Cochran waste-heat type, evaporated 0.84 pound of water per brake horsepower hour at from 60 degrees F. to steam at 100 pounds per square inch. A trial was made over a complete voyage, when it was shown that all the steam-driven auxiliaries, utilized on the ship, could be supplied from the boiler, and that the saving was equivalent to about 1½ tons of oil per day, which would otherwise have to be used under an oil-fired boiler. As the fuel consumption for the engines worked out at 5.35 tons, the economy was well over 20 per cent. It enables a remarkable result to be achieved, since the fuel consumption for the ship works out at 0.365 pound per shaft horsepower hour for all purposes.

The fear has been expressed that when raising steam in exhaust-gas boilers, a certain back pressure is placed on the engine. Trials were made with a view to ascertaining whether this actually occurred on the *Sheaf Holme*, when it was found that the difference in back pressure was quite negligible.

This design of boiler is arranged for simultaneous oil firing and exhaust-gas heating if necessary, with two separate nests of tubes, those in the exhaust-gas section being smaller than the others. The latter actually embodies two series of tubes, the gases first passing through the upper end and returning through the lower. All three series of nests are arranged between the same pair of tube plates.

The provision of exhaust-gas boilers on tankers is particularly desirable since, in many of the modern Diesel ships of this class, the auxiliaries are steam driven, for the reason that steam is, in any case, utilized for the large cargo pumps. It is found that even with two-stroke engined ships, sufficient steam can be raised by passing the exhaust gases through the boilers for operating all the steam auxiliaries needed when under way. The fuel consumption of the propelling engines therefore becomes the overall consumption for all purposes.

The majority of the Standard Oil tankers of large size recently ordered are to be equipped with exhaust-gas boilers of what is known as the Clarkson thimble-tube type, and in some cases, not only will they act as silencers but they will be combined with spark arresters. The ships in most instances are equipped with twin-screw, two-stroke, single-acting machinery, developing a maximum of 5000 shaft horsepower, or probably about 4300 to 4500 shaft horsepower in service. There are two combined boiler and spark arresters for each vessel, the diameter being 5 feet and the height 5 feet 6 inches, or 10 feet 9 inches, including the spark arrester. These boilers generate between them 1700 pounds of steam per brake horsepower hour, assuming the exhaust-gas temperature to be no higher than 500 degrees F., and they act as silencers so that no other special silencers are installed.

Actually, more steam than this could be generated if required. For instance, on the *Calgarolite,* which was the first ship to be equipped with silencer boilers of this class, trials were made which indicated that, with an exhaust temperature of only 485 degrees F., the amount of steam raised per boiler was 995 pounds at 100 pounds per square inch, while with an exhaust temperature of only 410 degrees F., the steam raised amounted to 690 pounds per hour for each boiler. In the case of a two-stroke engine with the temperature at 500 degrees F., and utilizing a boiler of this design, it is stated that an average estimate, if the full amount of the steam is required, is about half a pound of steam per brake horsepower hour raised at 100 pounds per square inch. This is equivalent to approximately 2 tons of oil burned under the boiler, and based on present prices, the saving in fuel oil thus attained pays for the cost of the boiler in about six months.

It may definitely be said that no passenger liner is now laid down without some means being taken for the recovery of the waste heat of the exhaust gases. The largest installation was on the *Britannic,* where 10,000 pounds of steam are raised per hour in five boilers, two for each main engine and one for the auxiliaries. A similar arrangement is being provided for the sister ship now under construction, while on the 20,000-ton Union Castle liner *Winchester Castle,* which has just been completed, there are three silencer boilers, two for the main engines, capable of raising a total of 10,000 pounds per hour and having a heating surface of 500 square feet. These boilers are 5 feet 6 inches in diameter and 18 feet overall in height, including the combustion chamber, and are fitted with oil-firing equipment for use when the engines are not in service.

On the P. S. N. Company's passenger liner *Reina del Pacifico,* which has machinery of 22,000 shaft horsepower, there are also three silencer boilers, and the two, fitted for the absorption of heat from the main engine exhaust gases, are each designed to raise 4000 pounds of steam per hour, although only taking 50 per cent of the exhaust gases.

Another line of development in passenger liners is the equipment of existing motor vessels with exhaust boilers. When, for instance, the R. M. S. P. Company's liners *Asturias* and *Alcantara,* also the Cosulich Company's liners, *Vulcania* and *Saturnia* were built, suitable exhaust-gas boilers had not been developed, and all the heat in the gases is lost. It is proposed to

provide the boilers now, and it is understood that the installation could be carried out so rapidly that no time would be lost and an enormous saving effected.

On cargo liners, similar developments are taking place. An instance of this is to be noted in the 14 to 15-knot liners of the Silver Line, operated by the Kerr Company, in which Harland & Wolff, single-acting, four-stroke machinery is installed. The arrangement is somewhat unusual, since there is only one silencer boiler, taking the exhaust gases from one of the main engines and 50 per cent of those of the second main engines. This is because only 3500 pounds of steam per hour are required, and the amount can easily be raised by the method described. The total machinery power in this ship is about 7000 shaft horsepower.

A still further application of the exhaust-gas boiler is to be found in recently constructed motor trawlers in Europe. Four such vessels were built in England some time ago with engines of 700 brake horsepower. In each was fitted a silencer boiler, which is capable of being run with or without water, and is fitted with an oil burner which may be used simultaneously with the exhaust gases, so that when the engine is running at reduced speed or not in use at all, sufficient steam can be maintained. Actually, although the engine is of the two-stroke type, the exhaust gases produce 800 pounds of steam per hour, and with auxiliary oil firing, a further 800 pounds of steam can be generated, making a total of 1600 pounds of steam per hour.

As one of the minor economies on motorships, if a saving of 5 per cent can be called a minor economy, the installation of exhaust-gas boilers on practically all vessels of this type is now bound to make headway and in the near future, probably 75 per cent of new oil-engined craft will be equipped with such heat and power saving auxiliaries.—"Marine Engineering and Shipping Age," November, 1930.

BRASSES, BRONZES AND ANTI-FRICTION WHITE METALS.

The engineer uses non-ferrous alloys in the construction of some of the components of machines because of their many valuable properties, of which the most useful are resistance to corrosion, high thermal conductivity and low frictional resistance. Not on account solely of their strength, nor because of their hardness, would their adoption be warranted, for the many varieties of carbon and alloy steels have greater claims to recognition in these respects. As engineering progress continues the demands increase, and become more exacting, for the production of metals with various complicated combinations of properties which cannot be obtained with any simple metal, and it is for this reason that metallurgists have devoted so much time and ability to the study of the non-ferrous alloys. Success in meeting most of the demands of engineers can be claimed, but the work continues, metallurgical progress keeping pace with the new requirements of engineering developments. It is always to the benefit of all, under such conditions, to make periodical surveys of the experiences gained in actual service with the materials adopted for specific duties. Such a survey was made by Mr. Wesley Lambert in a very useful paper he contributed on "Some Non-Ferrous Engineering Alloys," to a recent meeting of the Institution of Engineers and Shipbuilders in Scotland.

Considering first the yellow metal alloys, the author divided them into high tensile metals, almost entirely confined to manganese bronze and aluminium bronze, and the lower tensile binary alloys of copper and zinc, with or without the addition of small percentages of tin and other metals. To the well-known examples, naval brass, cartridge metal, muntz metal, and delta

metal, which forms the principal items in this second-class of alloys, has now been added a brass of the composition 76 per cent copper, 22 per cent zinc and 2 per cent aluminium, as a corrosion-proof material for condenser tubes. The enhanced mechanical properties of manganese bronze over those of common brass were in great part due to the presence of small percentages of tin, iron, manganese, aluminium, nickel and other metals. Great care was necessary in mixing, which was work for specialists. Foundrymen who have attempted compounding and casting direct, without the preliminary production of ingots, know this to their cost, but sometimes cast aspersions on all the complex brasses rather than acknowledge their own inability to recognize a well-established experience. The reasons for the failures are not far to seek: the temperatures used in making the alloys are in excess of those recognized as suitable for casting in the foundry and the absorption of gases is very dissimilar under the two conditions. Premature mixing commonly resulted in a lack of homogeneity, the presence of undissolved metal, abnormal melting losses of individual constituents, and it often caused segregations and other troubles in the finished products. Great strength was characteristic of the manganese bronzes and, because of their other valuable properties in association with this, such alloys found extensive use in the production of marine propellers, gland rings, conning-tower castings, torpedo tube casings, marine engine fittings, gun mountings and gear wheels.

Essentially an alloy of copper and aluminium, the copper predominating, aluminium bronze found service for parts of engineering equipment which were subjected to alternating or repetitive stresses. This resistance to fatigue, a feature separating these alloys from most others, was not the only property that determined the selection of the aluminium bronzes for their specific applications, for they possessed the valuable characteristic of resisting corrosion to an even greater extent than the manganese bronzes. As a casting material aluminium bronze was not much in favor, apart from die-casting, because of the troubles experienced with dross, shrinkage, gas cavities and patches of aluminium oxides, all of which were common causes of failure.

Gunmetal enjoyed great popularity among engineers, but not always so with foundrymen because of the difficulties sometimes experienced with it in casting. The standard composition of 88 per cent copper, 10 per cent tin, and 2 per cent zinc, specified for Admiralty gunmetal, was therefore occasionally deviated from, the foundryman increasing the zinc content to 4 per cent, or adding lead to its composition, to overcome his inability to make successful castings unless these unauthorized liberties were taken. Slipshod methods cannot produce good gunmetal, and contaminated scrap metal was entirely unsuitable for its compounding. In the process of manufacture, "best selected" ingot copper must be carefully melted under non-oxidizing conditions, followed by the introduction of the warm, dry zinc and gentle stirring; and lastly, after a short interval, the tin must be added. Phosphor bronze, in common with other special bronzes, contained the substance which gave it its distinctive name solely, or largely, as a scavenging agent. In some of these special bronzes the name-giving material may only be present to the extent referred to in analyses as "traces." The admiralty specification for phosphor bronzes called for the presence of 10 per cent of tin and not less than 0.3 per cent of phosphorus, the remainder being copper. It had been found, however, that where a high degree of resistance to wear and a low coefficient of friction were required, in combination with strength, the quantity of tin may well be increased beyond the admiralty figure and the phosphorus content may be put up to 1.5 per cent. These bronzes served as bearing metals, and showed on examination through the microscope the desirable hard patches somewhat regularly spaced and held together with

softer material, which was useful in that duty. Their uses were not solely confined to this sphere, for chill-cast and centrifugally-cast phosphor bronze was used for gear-wheel blanks.

There was not yet established any standard practice in regard to the metals for bearings, but the essential properties they must possess had been settled by experiment. It must be recognized, however, that the true criterion of the value of any metal for any specific duty was its behavior under actual practical conditions. An alloy was not necessarily a good bearing metal because it was soft, like the alloys of the babbitt class, or hard, like some of the bronzes. Low coefficient of friction, good conductivity of heat, combined with resistance to abrasive wear and the strength and rigidity to stand up to the duty, were the fundamental requirements. Elemental metals had proved to be unsuitable. Alloys were essential for this application, and the microstructure of the metal was much more important in their selection than chemical analysis. These bearing metals had a structure made up of alternate hard and soft constituents, distributed uniformly throughout the mass. The hard parts bear the load, the soft portions bind them together and form, by their greater wear, minute depressions in which a film of lubricant can be preserved. In the white metals hard cubical crystals of tin-antimony and star-shaped crystals of copper-tin were found, and these served to withstand the load. The distribution of these hard particles was the index to the value of these metals for bearings. Under such conditions proper compounding was the first essential. To meet the exacting requirements of high-speed, heavy-duty machinery the tin-base babbitt metals were recommended for specification, notwithstanding that the question of lubrication had been carefully studied and successfully met. For equal hardness a lead-base metal was more brittle than a tin-base alloy. This was an undesirable feature, as it might lead to failure through cracking and the breaking away of the lining metal from the shell.—"Shipbuilding and Shipping Record," Dec. 18, 1930.

EFFECT OF METALLIC COATING UPON FATIGUE.

There is a growing tendency to make use of electro-deposition to build up worn parts and to provide a wear and corrosion-resisting surface. The process is in many cases far cheaper than replacement. Nickel is commonly used on steel parts on account of its similarity in mechanical properties and on account of its resistance to corrosion.

R. H. D. Barklie and H. J. Davies publish in "The Engineer" (December 19, 1930, page 670) the results of their investigations of the effect of electro-deposited metal upon the fatigue properties of the original metal, and their conclusions are reproduced herewith in full:

1.—Tensile stress in nickel, electro-deposited on a steel test piece, which is subjected to a fatigue test, acts like a mean stress and seriously reduces the fatigue limit.

2.—The mechanism of this reduction is (a) the formation of a crack in the nickel layer under the combined influence of its own tensile stress and of the stress applied in the test; (b) the concentration of stress at the base of this crack.

3.—The reduction in the fatigue limit is greater than that produced by a circular nick of depth equal to the thickness of the nickel deposit. The nickel, being in a state of internal stress, will exert an influence tending to widen the crack. Thus the concentration of stress at the base of the crack in nickel is greater than that of the base of a crack in steel.

4.—The difference between the effects of circular nicks and stressed nickel deposits diminishes as the thickness of the deposit and the depth of the nick are decreased. This is in accordance with conclusion 3.

5.—Electro-deposits of nickel having little internal stress have a greatly reduced influence on the fatigue range of steel. The conditions for the electro-deposition of nearly stress-free nickel are described. It is advisable to use such deposits for building up, especially when the thickness exceeds 0.001 inch.

6.—Electro-deposits of copper free from internal stress reduce the fatigue limit of steel. This is in accordance with the fact that the tensile strength of copper is less than that of mild steel, so that a range of stress without influence on steel would crack copper.

7.—Electro-deposits of zinc having a slight internal stress causing them to expand do not lower the fatigue limit of steel. This is in qualitative agreement with conclusions 1, 2, 3, and 6.

8.—Electro-deposits of lead are without serious influence on the fatigue range of steel. We consider the effect of the low-tensile strength to be offset by the fact that a concentration of stress greater than the low-tensile strength of lead cannot arise at the base of a nick in the lead sheath.

9.—Intermediate lead films between stressed nickel and mild steel have been found to insulate the steel core from effect of stressed nickel deposits. Films as thin as ten-millionths of an inch have been found to have this property. Such films may have considerable value where it is essential to eliminate all risk of failure due to cracking of a deposit.

10.—As the thickness of the intermediate lead film is reduced the apparent adhesion of the nickel deposit is increased. Using very thin lead films, the appearance of the fracture of a Wöhler test piece is similar to that of a test piece in which the nickel is plated directly upon steel.

11.—Certain processes preliminary to electroplating have been found to destroy the mechanical continuity of the surface layers of a steel strip.

12.—Circumferential grooves have a much more serious effect on the safe range of stress in hard steel than similar grooves in mild steel. The concentration of stress even in the hard steel is still well below that for elastic material.

13.—For a groove of given root radius there appears to be a limiting depth, beyond which greater depth has no further influence on the resistance of the steel to repeated stresses.

THE MACHINERY INSTALLATIONS OF THE LINER *BREMEN* AND ITS PREDECESSORS*

By Professor G. Bauer, Translated by E. C. Magdeburger.

Main steam piping deserves particular mention, because the *Bremen* has no doubt the first marine installation of such large power, using at the same time superheated steam of so high a temperature.

The expansion joints, such as have been successfully used with sliding, turning, spherical and linkage glands on the mighty main steam pipes of the old express liners for saturated steam could not be considered, because such constructions are subject to seizure with superheated steam and can be used only in the simplest cases and with great caution. In the subject installation, therefore, elongation due to temperature was taken care of in the superheated steam mains by extensive use of expansion loops, which will be described later.

* Continued from page 717, Journal A. S. N. E. Nov., 1930.

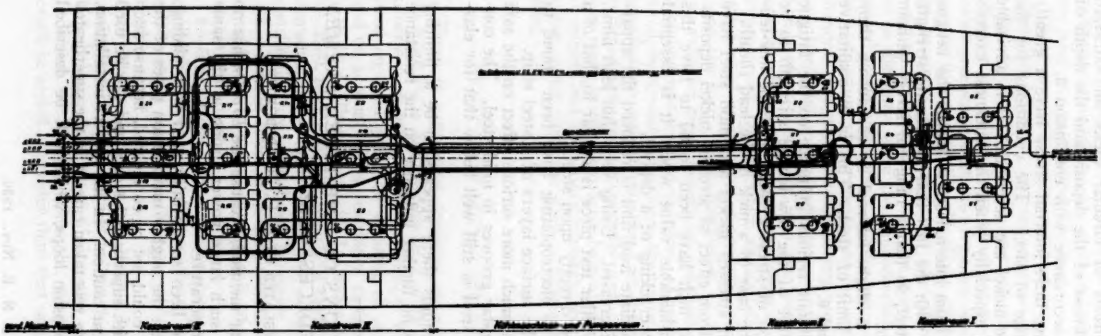


Figure 28. Diagrammatic plan of Steam Piping in the Firerooms.

—— Superheated steam mains	⊢⊗⊣ Stop valve	S. Bulkhead stuffing box	
—— Superheated steam-boilers to mains	M⊢⊗⊣ Mixing Valve	vord.Masch.Raum-ford.Engine Room	
—— Superheated steam for auxiliaries	⊢◎⊣ Water separator	Kesselraum - Fireroom	
– – – Saturated steam for auxiliaries	F Fixed point	Kühlmaschinen - Ice Machines	
– – – Saturated steam - boilers to mains	S.V. Safety Valve	Pumpenraum - Pump Room	
K⊢⊗⊣ Boiler Stop valve operated from work.platform	Res. Reserve Connection	Dampfrohrtunnel - Steam Pipe Tunnel	
F.B⊢⊗⊣ Stop valve with distant control	n.H. to auxiliaries.	Deckhilfsmaschinen - Deck Auxiliaries	

The general arrangement of the main steam piping is shown diagrammatically in Figure 28.

All the steam mains may be subdivided into three groups according to their purpose, and these are led independently through the engine and fire rooms, but may be interconnected should it become necessary or desirable.

The first group contains the main steam pipes for the main propelling turbines. These pipes have an internal diameter of 325 millimeters (12.795 inches), one pipe leading from each fire room to one of the turbine units—the forward firerooms supplying steam to the forward engine room, while the after boiler rooms feed the turbines of the after engine room.

To the second group belongs the superheated steam piping for the larger auxiliaries, consisting of two pipes—the one leaving the forward firerooms I and II is of 200 millimeters (7.874 inches) internal diameter up to the fireroom IV, where it is connected to all the boilers of this fireroom; from here it leads with an internal diameter of 225 millimeters (8.858 inches) to the valve box on the forward engine room bulkhead. Fireroom III has a separate auxiliary steam pipe also of 225 millimeters (8.858 inches) internal diameter, which is laid amidships as a straight pipe direct to the valve box on the engine room bulkhead.

The above two pipes are interconnected in fireroom III by an auxiliary-steam connecting pipe of 140 millimeters (5.512 inches) diameter to each other and by means of shorter pipes with expansion loops to the main steam pipes in firerooms III and IV. The pipe leads are easily seen on Figure 28.

The third group contains the saturated steam piping: a single pipe leads from the forward firerooms I and II through the pipe tunnel to fireroom III and continues from there as a circuit in fireroom IV and in both of the engine rooms. All boilers are connected to this auxiliary saturated steam piping through the pressure-equalizing valves on the steam domes. Connections from this saturated steam system are made to both of the superheated steam systems at their respective collector manifolds.

While the main superheated steam pipes could be interconnected only at the engine room bulkhead (where large water separators are also installed) and led direct to the main turbines without any kind of branching underway, the auxiliaries are fed from the mains of the auxiliary steam piping through branches, which could be shut off in groups by means of a special valve.

Of particular importance were the choice of a suitable material for the piping and the design of a reliable joint between the individual pipe lengths.

One of the most important points is the joint between the flanges and the pipe itself, also between the flanges themselves; in order to proceed absolutely sure in this respect, different types of construction were subjected to practical tests to determine their reliability before they were installed in the ship. The flanges were made particularly strong and as material was chosen steel of 50 to 55 kilograms per square millimeter (71,000-78,000 pounds per square inch) while the bolts were made of an especially high quality chrome-nickel steel of 90 to 100 kilograms per square millimeter (128,000-142,000 pounds per square inch) tensile strength. The pipes were rolled into the grooves, made in the bore of the flanges, and their ends expanded subsequently.

The collecting manifold of each group of boilers was made the highest point of each steam pipe and the pipe made to drop gradually in both directions, to the boilers and to the engine room bulkhead, where large water separators were installed.

The manifolds on the forward engine room bulkhead serve as fixed points for all pipes leaving the firerooms and for those from the after firerooms they are their only fixed points. In places, where the last named pipes pass

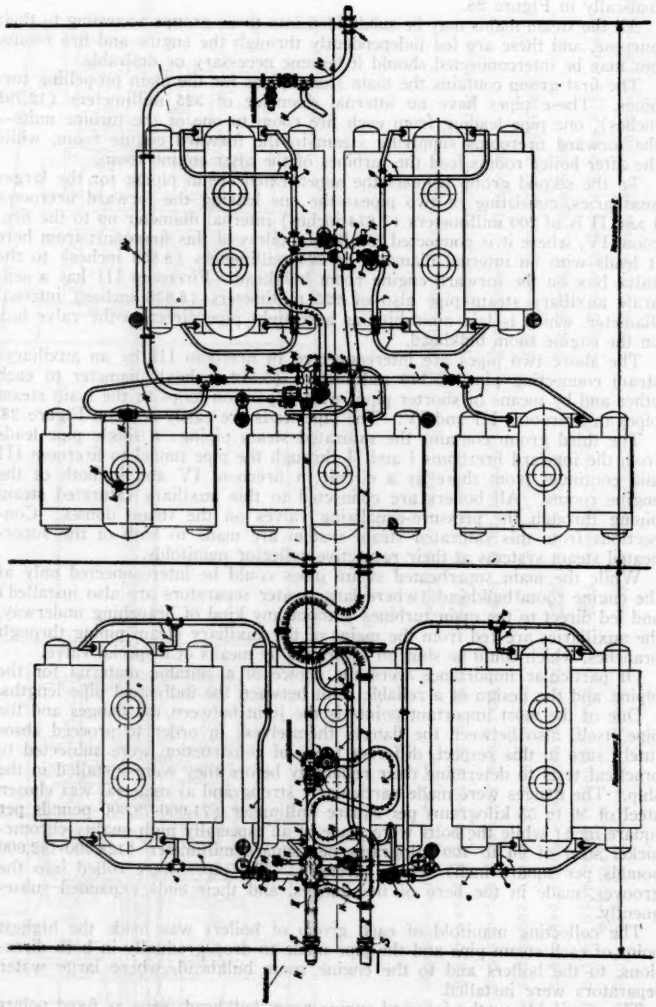


Fig. 29. Steam Pipes in the Firerooms I and II.

Legend to Fig. 29.

Nach Hilfsmaschinen - to auxiliaries.

I - Steam main from fireroom I to starboard turbine in forward engine room - 12.795" dia.

II - Steam main from fireroom II to port turbine in forward engine room - 12.795" dia.

III- Steam main from fireroom III to starboard turbine in after engine room - 12.795" dia.

IV - Steam main from fireroom IV to port turbine in after engine room - 12.795" dia.

H - Steam pipes to auxiliaries - 7.874" and 8.858" dia.

H_V - Steam pipes - 6.3" dia. to forward deck auxiliaries.

N - Saturated steam piping.

V - Connections - 7.874" and 8.858" dia. between main and auxiliary steam pipes.

Kesselraum - Fireroom.

V_h- Connections - 5.51" and 8.858" dia. of the auxiliary piping in firerooms III and IV.

F - Fixed points of main and auxiliary steam pipes.

K - Main stop valve on boiler.

M - Mixing valve between superheated and saturated steam systems.

S - Bulkhead stuffing boxes.

a - Collecting manifold of main steam pipe.

b - Collecting manifold of auxiliary steam pipe.

c - Tee-connection of superheaters of individual boilers.

d - Tee-connection in the superheater piping of boiler.

Dampfrohr tunnel - Steam Pipe Tunnel.

e- Cross-connection between main and auxiliary steam pipe systems.

f- Cross-connection between auxiliary steam systems.

g- Stop valves of individual boilers.

h- Stop valves in the auxiliary steam.

i- Stop valves in the cross-connection between main and auxiliary steam.

k- Stop valves in the cross-connection of the auxiliary steam systems.

l- Superheater collector pipes of individual boilers - 4.33" and 5.51" dia.

z- Cross-connections between main collecting manifolds of main and auxiliary steam and the superheater piping of individual boilers - 5.51" and 7.874" dia.

through the bulkhead, separating the after two firerooms, bulkhead stuffing boxes are provided, through which these pipes may freely slide when expanding under heat.

For the steam pipes coming out of the forward firerooms, however, this bulkhead serves also as a fixed point, and besides another fixed point is provided in the shape of a substantial pedestal in the center of the pipe tunnel between the two groups of firerooms. The pipes leaving fireroom I have an additional fixed point in the manifold on the bulkhead dividing the two forward firerooms.

From these fixed points the steam pipes when under steam slide in both directions, and due to the high temperatures of the steam the expansion is quite considerable.

To get the right conception of the amount of expansion that has to be dealt with, attention is invited to the conditions as they exist on the *Bremen*, *i.e.*, steam temperature of nearly 400 degrees C. (752 degrees F.) and a total length of pipe of about 100 meters (328.09 feet) and the total expansion of a steam pipe like that with complete freedom to expand will be about 60 centimeters (23.622 inches). To permit such sliding, which, of course, is made possible by special means for hanging-up and supporting the pipe, no expansion joints were used, as already mentioned, but expansion loops exclusively, the location of which on the individual pipes is shown on Figure 28.

To obtain the largest amount of deflection in the expansion loops these were made for the larger size of pipe according to the system employed with the so-called "folded pipes," which is shown to scale on Figure 29.

The calculations of the loops to absorb the heat expansion in the piping were based on thoroughly scientific principles, the exposition of which space will not permit.

The main steam piping to each turbine set leads from the large individual stop valves on the forward engine room bulkhead through an expansion loop to a main throttle valve, of which those in the forward engine room are hung up to the deck above, while in the after engine room they are incorporated into the operating stand and supported by pedestals and stanchions (Figure 30).

The steam, before entering the housing of the main throttle valve, passes through a quick-closing valve, which is installed immediately before the former. The principle of operation of this Aspinall quick-closing valve is to admit steam pressure, acting upward on the valve disk, by means of a by-pass pipe to the upper side of a piston, which is attached to the same valve stem and is of a larger diameter than the valve disk, so that the steam pressure itself closes the valve. This happens only then, of course, when the by-pass is open, while under normal conditions the by-pass is kept closed by a small regulating valve in that pipe, which is operated by oil pressure and thus keeps the steam path to the main throttle valve open. Should the oil pressure drop for any reason whatsoever, through operation of the quick-closing valve, through failure of lubricating oil pumps, etc., the steam supply to the turbines is immediately shut off (see Figure 31).

After passing the quick-closing valve the steam enters the upper part of the housing of the main throttle valve above the two similar valve disks, controlling steam supply to ahead and astern turbines. Figure 32 shows several sections through the valve housing, as built for the port unit of the forward engine room.

In addition to the steam inlet flange A the housing has the steam outlet flange D for ahead operation, through which the steam passes over a stuffing box into the high pressure turbine, and two flanges E_1 and E_2, connecting to the nozzle boxes of the astern turbine. Connection F serves for warming

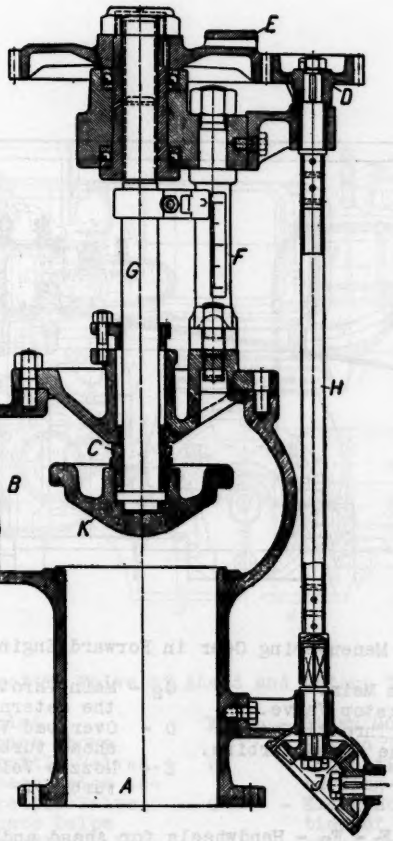


Fig. 30. Bulkhead valve in the Steam Mains.

A - Steam Inlet.
B - Steam Outlet.
C - Valve Disc Nut.
D-E-Gear Drive.
F - Column and Stem Guide.
G - Valve Stem.
H - Operating Gear
J - Bevel Gears.
K - Valve Disk.

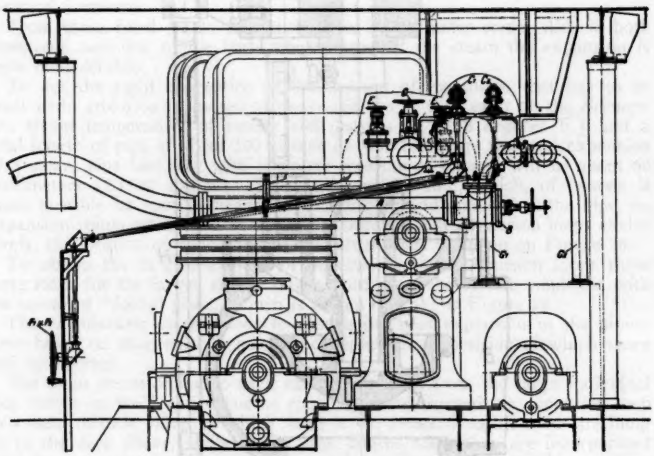


Fig. 31. Maneuvering Gear in Forward Engine Room.

A - Steam Main.
B - Quickstop Valve.
C_1 - Main Throttle valve of the ahead turbine.
C_2 - Main Throttle Valve of the astern turbine.
D - Overload Valve of the ahead turbine.
E - Nozzle Valves of Ahead turbine.

F_1 - F_2 - Handwheels for Ahead and Astern Throttle Valves.
G_1 - G_2 - Steam Pipe for Astern Throttle to Astern Turbine.

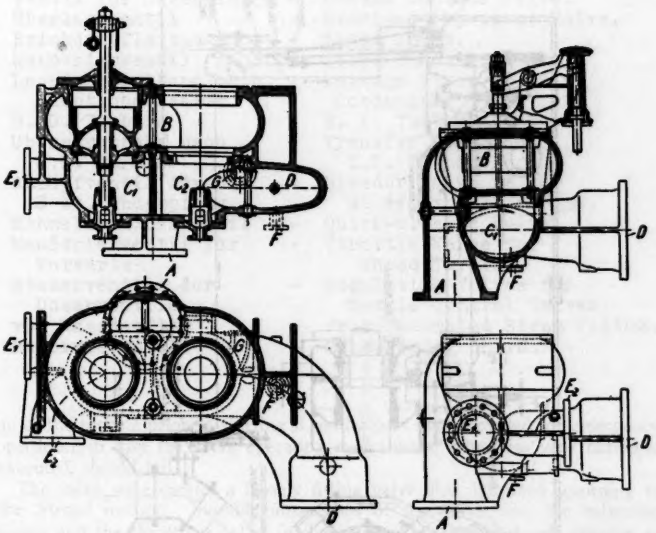


Fig. 32. Throttle Valve of Ahead and Astern Turbines.

A - Steam Inlet.
B - Steam Space above both Throttle Valves.
C_1 - Steam Space below Astern Throttle Valve.
C_2 - Steam Space below Ahead Throttle Valve.
D - Steam Outlet to Ahead Turbine.
E_1-E_2 - Steam Outlet for Astern Turbine.
F - Connection for warming-up steam.
G - Emergency connection of the steam space B with Space C_2

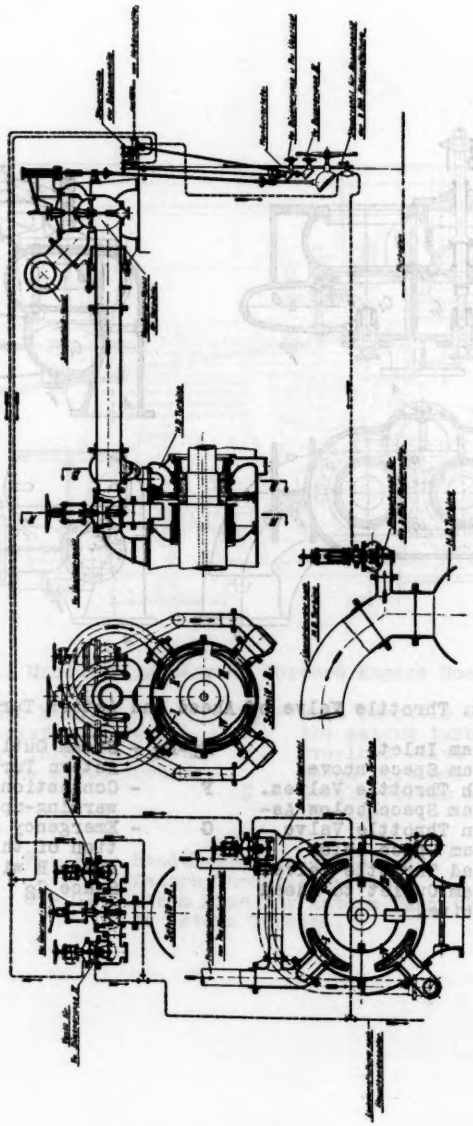


Fig. 33 - Diagram showing Nozzle Control Valves and Their Operation.

Ventil für Düzengruppe	-	Nozzle Control Valve.
Überlastventil	-	Overloed (by-pass) Valve.
Frishdampfleitungen	-	Steam Inlet.
Manövrierventil	-	Steam Throttle Valve.
Leckdampfleitung nach Hauptkondensator	-	Leakage Steam to Main Condenser.
H. D. Turbine	-	H. P. Turbine.
Überstromrohr nach M.D. Turbine	-	Transfer Pipe to I.P. Turbine.
Anzapfventil für die 3 at. Abdampfltg.	-	Bleeder Valve to the 42.6# Exhaust Piping.
Schnellschlussventil	-	Quick-closing Valve.
Manövrierventil für Vorwärts	-	Throttle Valve for Ahead Turbine.
Steuerventile der Düsenventile	-	Regulating Valves for Nozzle Control Valves.
von Nassdampfltg	-	from Saturated Steam Piping.
Manövriertafel	-	Maneuvering Board.

up of the turbine prior to starting it up, by-pass G is provided for emergency operation, in case the valve operating mechanisms, otherwise very carefully executed, should fail.

The valve stem carries a loosely fitting valve disk, balanced according to the Strnad method. Suitable dimensions of the valve seat, the balancing piston and the throttling collar in the housing guarantees a soft opening of the valve and an even flow of steam. A simple interlocking arrangement prevents the simultaneous opening of both valves for ahead and astern operation.

The path of steam from the valves to the blading is schematically shown on Figure 33.

For ahead operation the steam first passes through the straight pipe between throttle valve and turbine. The expansion of this piece of pipe is taken care of by a stuffing box, the only one in the whole steam piping. Huhn metallic ring packing was chosen for this important duty after extensive tests.

Out of the distributor box before the valve housing of the H.P. turbine the steam, after passing a separator, enters the nozzle boxes 1 and 2. This supply of steam is, however, sufficient only for operation at half-speed and in order to reach the normal full-speed the nozzle boxes 3 and 4 must be also supplied with steam. This is done by opening both of the nozzle control valves, through unloading the balance pistons on the stem of each valve from the operating stand. Before the steam enters the nozzle box it must pass here also through a steam separator.

Should it be desirable to increase the speed of the ship still further and above the normal full-speed, it is possible to permit more steam to enter the H.P. turbine, by by-passing its impulse stage, through a manually operated overload or by-pass valve, arranged between the two above mentioned nozzle control valves and directly above the impulse wheel chamber.

For astern operation there are also two stages of operation provided. With the main throttle valve open the steam enters direct into the nozzle groups 1, 2 and 3 of the impulse stage arranged in the I.P. turbine housing. A higher speed astern is secured by opening a steam operated astern overload or by-pass valve, controlling steam to nozzle box 4. Steam separators are provided before all four nozzle boxes.

Feed water heating is done in the customary way by means of exhaust steam from the auxiliaries and the connection of the various steam pipes and corresponding auxiliary apparatus was so chosen that the heat contained in the exhaust is utilized in the most efficient manner, *i.e.*—the exchange of heat between the exhaust steam and feed water is carried out with the smallest possible temperature drop.

It was necessary for this purpose to have piping of different back pressures, varying from 1 atmosphere * (14.2 pounds) to 3 atmospheres (42.6 pounds), and connect auxiliaries accordingly. The 3 atmosphere (42.6 pounds) back pressure exhaust system received besides a connection to the I.P. turbine housing, so that steam could be bled from there when necessary.

The diagrammatic sketch shown on Figure 34 clearly illustrates the existing conditions and will be continuously referred to in the following.

The 3 atmosphere (42.6 pounds) back pressure exhaust piping extends through all the engine and firerooms as well as the pump room and receives the exhaust not only of all auxiliaries in the firerooms and pump room but also the exhaust of main circulating water pumps and engine room blowers installed in the engine rooms. The capstan engines in the bow and stern of the vessel and the steering engine are also connected to this same exhaust piping. All of these auxiliaries with the exception of circulating water pumps, which are shown separately, are designated by R in the diagram, Figure 34.

The 1 atmosphere (14.2 pounds) back pressure exhaust piping receives the exhaust of all auxiliaries installed in the engine rooms, with the exception of the above mentioned blowers and circulating water pumps and to it is connected also the exhaust of the evaporators.

The steam of the above two exhaust systems is used to heat feed water in two stages, the feed water being pumped by feed water pumps O into the I stage of heater installed in the engine room, where its temperature is raised from 42 degrees C. (107.6 degrees F.) to 92 degrees C. (197.6 degrees F.) by the exhaust steam out of the 1 atmosphere (14.2 pounds) system, while the 3 atmosphere (42.6 pounds) exhaust system is connected to the II stages of the heaters installed in the firerooms, where its temperature is raised to 125 degrees C. (257 degrees F.) and from where it is delivered to the boilers.

The above mentioned initial temperature of the feed water in the hot well results from mixing of condensate out of the drain pockets, which are all

* In the Metric system 1 at. = 1 kilogram per square centimeter = 14.2 pounds per square inch.

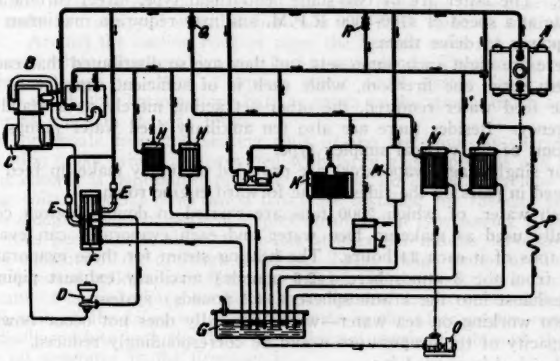


Fig. 34. Diagram of Feed Water Heating.

——— Fresh Steam.
——— Exhaust Steam (42.6#)
——— " " (14.2#)
wwwwwww Vapor
A - Boiler
B - Main Turbine
C - Main Condenser
D - Condensate and Drain Pump
E - Steam Jet Air Pump I and II Stages.
F - Intermediate Condenser and Preheater of Steam Jet Air Pump.
G - Hot well.
H - Hot water systems (Salt and Fresh).

——— Condensate.
——— Feed Water.
..... Raw Water.
------ Hot Water.
J - Main Circ. Water Pump.
K - Evaporator Plant.
L - Vapor Preheater.
M - Fuel Oil Heating.
N - Feed Water Heaters I and II stages.
O - Main Feed Water Pump.
P - Heating, Galley, etc.
Q - Auxiliaries of 14.2# back pressure.
R - Auxiliaries of 42.6# back pressure.

connected to the hot well, with the condensate of the main turbines, which comes out of the main condensers at about 25 degrees C. (77 degrees F.) and is heated up to 33 degrees C. (91.4 degrees F.) by the exhaust of the steam jet pumps.

The hot well is arranged amidships under the deck of the forward engine room and the condensate passes from there direct to the main feed pumps below. The latter are of two-stage centrifugal type, direct turbine driven, operate at a speed of 4700-5000 R.P.M. and may require a maximum of 300 horsepower to drive them.

There are eight such pump sets and they are so distributed that each two of them serve one fireroom, while each is of sufficient capacity to supply all the feed water required, the other set acting merely as a stand-by or emergency. Besides there are also ten auxiliary feed water pumps in the firerooms of the vertical simplex type.

Four single-stage evaporators are provided to supply make-up feed water, arranged in pairs on the sides of the forward engine room.

Fresh water, of which 2000 tons are carried in double bottom cells, is normally used as make-up feed water and each evaporator can evaporate 75-84 tons of it each 24 hours. The heating steam for these evaporators is taken from the 3 atmosphere (42.6 pounds) auxiliary exhaust piping and they exhaust into the 1 atmosphere (14.2 pounds) system.

When working on sea water—which normally does not occur however—the capacity of the evaporators would be correspondingly reduced.

Boiler fuel is carried in:

12 Double bottom tanks of a total volume of 2702 cubic meters (714,000 gallons.)

13 Gravity tanks totaling 2,595 cubic meters (685,000 gallons) and 9 day tanks (settling tanks) totaling 1773 cubic meters (468,000 gallons), of the latter there are two in fireroom I, two in fireroom II, three in fireroom III and the remaining two in fireroom IV.

The total available space for carrying boiler fuel is 7070 cubic meters (1,870,000 gallons.)

In addition to the above named tanks there are also 3 overflow tanks, two of which are high tanks and the third is in the double bottom, which, when 75 per cent filled, have a volume of 240 cubic meters (64,600 gallons), and two dirty oil tanks, which can accommodate an additional 158 cubic meters (41,700 gallons) when 100 per cent filled.

All the day tanks are arranged amidships, otherwise the trim of the ship would be changing continuously if they were supported by the skin of the ship, besides the latter arrangement would require more steam for heating up the oil. To prevent leakage oil from spreading over the whole flooring the high tanks are surrounded by leakage oil trench and a well from where the accumulated oil is pumped out by special pumps.

Each fuel tank has two stop valves, one of quick-closing type directly on the tank operated from the adjoining compartment, and an ordinary stop valve in the change-over valve box.

Besides all gravity tanks have quick-closing valves of 40 millimeters (1.575 inches) clear diameter, by means of which any water that may have accumulated on the bottom may be drained into the corresponding leakage trench.

Each supply and day tank is equipped with a vent pipe of 150 millimeters (5.9 inches) internal diameter, which prevents the adjoining tanks from being filled after the filling of one is completed, the upper end of this pipe is carried up to the deck above and serves at the same time as an overflow pipe, carried down to one of the 3 overflow tanks (expansion tank) belonging to this group of tanks. The overflow tanks are provided with particularly large vent pipes (250 millimeters or 10 inches diameter) and have floats, actuating electric alarm signals, when these are three quarters full.

All tanks are equipped with heating coils and fresh steam is used to heat the oil. Around the suction ends of pipes the heating coils are arranged in four rows, while otherwise they are laid in one plane. The heating surface provided amounts to about .1 square meter (1.08 square feet) per ton of oil in the double bottoms, one half as much in the supply tanks and one quarter as much in the day tanks.

The condensate from the heating coils of the fuel tanks is carried into observation tanks, which are provided with large glass openings and a continuous control is maintained to make sure that no leakage develops in the heating coils. Special observation tanks are installed for the day tanks.

Two sludge pumps of vertical duplex-steam-pump type having a capacity of 12 tons per hour at about 10 double strokes per minute serve to pump out the contents of the drainage trenches. These sludge pumps are installed on the forward bulkheads of firerooms II and III, their suction is connected by means of special piping to the wells in the draining trenches and also to the oil tank of the bilge water oil separator in the after engine room and they discharge into both the dirty oil tanks and overboard through the bilge water oil separator in the fireroom I.

Fuel supplies are taken on board in both end ports Bremerhaven and New York; occasionally small amounts of fuel are taken also during the brief stay at Southampton.

Two large fueling ports on each side of the ship, which may be opened from the bunkering compartments of the firerooms II and III, are provided for the purpose of bunkering the necessary fuel supply. At Bremerhaven only the bunkering compartments toward shore are used. A full normal supply of 5000 tons of bunker oil can be taken over in 7 hours by means of two lines of hose. The oil being bunkered is first passed through large filter in the bunkering compartment and from there into the filling pipe system, which is of 250 millimeters (10 inches) in diameter and extends from the bow up to fireroom IV. This pipe system serves also as suction piping for the four bunker oil transfer pumps, which either transfer the fuel from any of the tanks to the day tank or to any other tank for the regulation of the trim of the ship. These transfer pumps are of the simplex type and have an hourly capacity of 120 tons.

A special provision made for the gravity tanks and 4 double bottom tanks deserves mentioning. These tanks are connected to the discharge piping of the circulating water pumps of the refrigerating system and may be filled with sea water after their bunker oil contents have been removed in order to be able to regulate the center of gravity and the trim of the ship. These tanks can be again emptied by pumping with main bilge pumps to which they are connected.

In each of the four firerooms are installed two twin suction strainers, two fuel oil service pumps, two fuel oil heaters, two air chambers and two twin pressure filters. The fuel passes through the above mentioned auxiliaries in the order mentioned. Two pipes lead from the change-over valve boxes, arranged after the pressure filters, to the boilers, one of these is the main service pressure line, while the other serves as a reserve. This latter

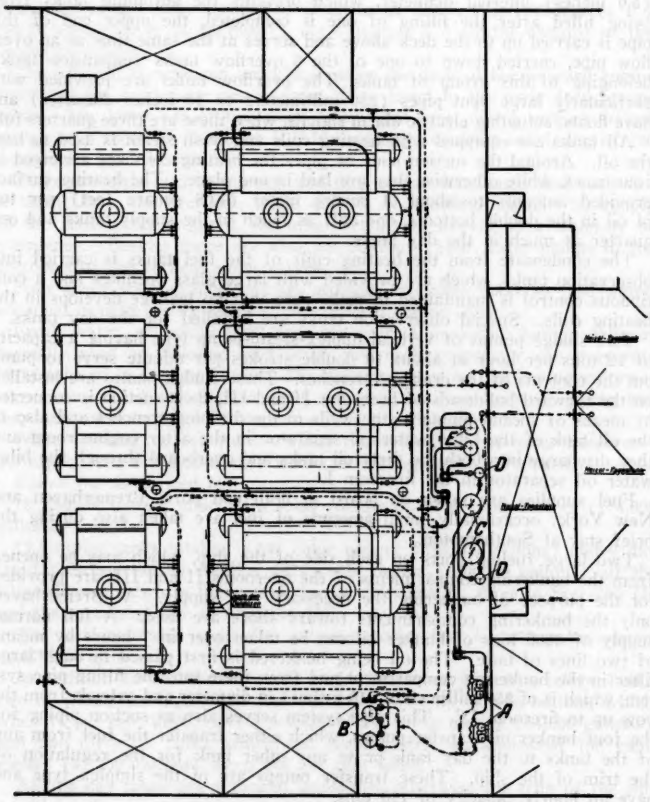


Fig. 35. Fuel Oil Service Piping in Fireroom III.

——— Suction Piping of Fuel Service Pumps.
——— Pressure Piping of Fuel Service Pumps.
----- Transfer and Reserve Pressure Piping of Fuel Service Pumps.
A - Fuel Oil Service Pumps (Duplex)
B - Fuel Oil Suction Strainer.
⊗ Stop Valve
Ø Quick Closing Valve.
Heizöl-Tagestank - Day Tank.
Nach den Oeldüzen - to the burners.
C - Fuel Oil Heater.
D - Air Chamber in the Pressure Fuel Oil Piping.
E - Pressure Filter.

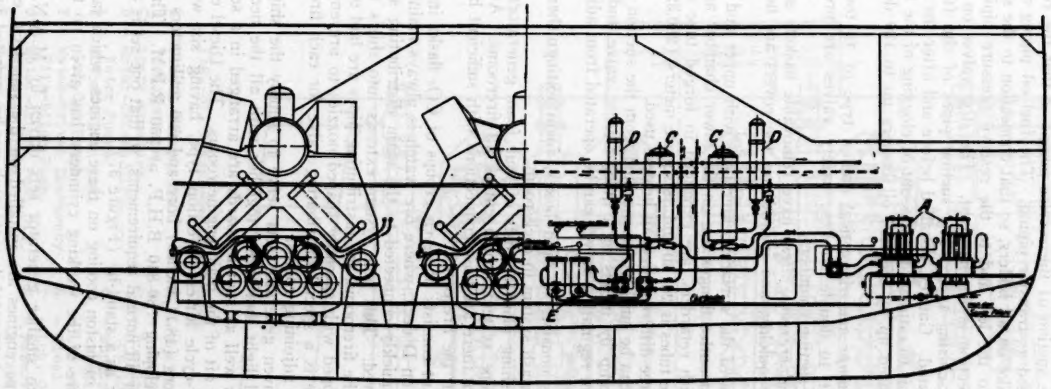


Fig. 36. Fuel Oil Service Piping in Fireroom III.

A - Fuel Oil Service Pumps (Duplex)
C - Fuel Oil Heaters.
D - Air Chamber in the Pressure Fuel Oil Piping.
E - Pressure Filter.

piping is connected to the suction of the service pumps so that the reserve pressure piping can be used as transfer piping. The fuel oil piping on the boiler fronts is exactly alike on all boilers, so that connection to the service pressure line is always to the left and to the reserve pressure piping or transfer piping, the connection is to the right. The stop valves on these systems are of the quick-closing type. The suction pipes of the fuel oil service pumps may be heated. Gauges, installed before and after the filters (Figures 35 and 36) permit to estimate the amount of clogging of the filters.

The fuel oil can be heated up by the fuel oil heaters up to 120 degrees C. (248 degrees F.).

The fuel oil service pumps are of vertical duplex type of 12 tons per hour capacity with about 10 double strokes; safety valves are provided between the pressure and suction chambers.

The fuel oil suction and pressure filters have removable baskets so that they can be cleaned very quickly, and in addition the covers are held by swing bolts.

The fuel oil heaters are of the surface heater type with upper and lower chambers. Both inlet and outlet flanges are on the lower chamber and the heater tubes, equipped with retarders, are expanded in forged tube sheets. The heating surface of the tubes is 26, 30 and 38 square meters (280,323 and 410 square feet) in the three different sizes of heaters used.

Each fuel oil day tank can be quickly disconnected from the suction piping of the fuel oil service pump by means of a quick-closing valve and these valves as well as the steam regulating valves can be operated from adjoining rooms.

Fire fighting apparatus consists of sand boxes, foam extinguishers and hose connections to deck wash system in each room.

The foam fire extinguishing plant consists of four foam generators, connected to one common pipe system, which enters all firerooms. At each fireroom working platform there are hose connections with sufficient hose to distribute foam throughout the fireroom.

The carbon dioxide plant consists of seven groups of CO_2 flasks installed in a well protected room on D deck, where fire watch is always maintained, and these flasks can be quickly connected to the main distributing system, when a fire call is received. This pipe system extends into ship's rooms, Diesel engine room, and the firerooms, the distributing pipes are laid over or under the floor and equipped with specially shaped nozzles to prevent their clogging with ice. There is a special distributing valve for each fireroom, operated from one of the adjoining rooms.

Four Diesel engine driven generator sets serve to supply the ship's requirements in power and light and these, together with all the necessary auxiliaries, tanks, etc., as well as switch boards are arranged in a separate engine room, immediately aft of the main engine rooms. The Diesel engines are of the M.A.N. four-cycle airless injection type, having six working cylinders of 460 millimeters (18.11 inches) bore and 600 millimeters (23.62 inches) stroke, each developing 780-840 B.H.P. at 250 R.P.M. Three of these sets are sufficient for all normal requirements, so that one set is always available for inspection or as a stand-by (Figure 37).

Of interest is the lack of piston cooling on these engines, which fact, despite the rather large bore of the working cylinders, has given no trouble whatever so far.

For emergency use two smaller generator sets driven by M.A.N. four-cycle airless injection type engines are installed on the sun deck, each of these has a rated output of 80-100 kilowatts and can be operated independently of anything else on the ship.

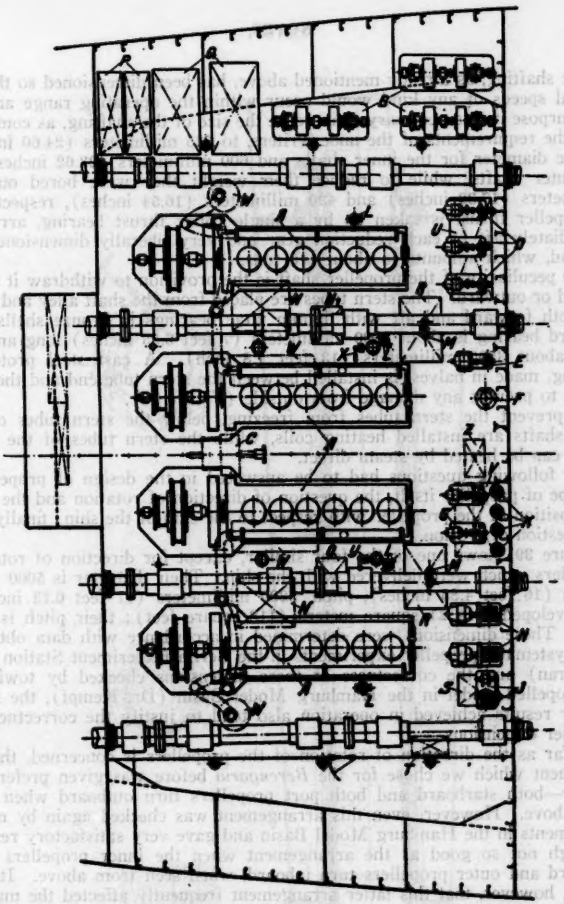


Fig. 37. Diesel-Generator Room

A - Diesel Generators.
B - Transformers.
C - Spare armature.
D - Motor-driven Circ. Water Pumps.
E - Motor-driven Aux. Lub.Oil Pumps.
F - Motor-driven Emergency Fire-Bilge Pump.
G - Motor-driven Fuel Oil Service Pumps.
H - Motor-driven Auxiliary Air Compressors.
J - Motor-driven Lub.Oil Centrifuges.
K - Starting Air Flasks.
L - Oil Coolers.
M - Fuel Oil Filters.
N - Fuel Oil Day Tank.
N_1 - Fuel Oil Leakage Tank.
O - Lub. Oil Leakage Tank.
P - Supply Tanks for Engine Cylinder Oil.
Q - Supply Tanks for Engine Bearing Oil.
R - Lub. Oil Sumps.
S - Clean Oil Tanks.
T - Lub. Oil Heating Tank.
U - Reserve Lub. Oil Supply Tank.
V - Dirty Oil Tank.
W - Muffler.
X - Fuel Leakage Oil Hand Pump.
Y - Lub. Leakage Oil Hand Pump.
Z - Switchboard.

The shafting, as already mentioned above, has been dimensioned so that no critical speeds of any kind would occur within the operating range and for this purpose it was necessary to increase the size of the shafting, as compared with the requirements of the underwriters, to 625 millimeters (24.60 inches) outside diameter for the inner shafts and 600 millimeters (23.62 inches) for the outer shafts, while to reduce their weight they were bored out 440 millimeters (17.32 inches) and 420 millimeters (16.54 inches), respectively.

Propeller thrust is taken up by a single collar thrust bearing, arranged immediately aft of each reduction gear and very liberally dimensioned for its load, which amounts to about 110 tons.

The peculiarity of the propeller shaft is the provision to withdraw it either inward or outward. The stern tubes are placed from the shaft alley and fitted out both forward and aft with lignum vitae bearings in bronze shells; the forward bearing is about 2300 millimeters (7 feet 6.55 inches) long and the after about 3500 millimeters (13 feet 1.8 inch). A cast steel protective housing, made in halves, is installed between the stern tube end and the propeller, to prevent any damage from outside (Figure 38).

To prevent the stern tubes from freezing, below the stern tubes of the outer shafts are installed heating coils, while the stern tubes of the inner shafts can be heated by steam direct.

The following questions had to be answered in the design of propellers: the type of propeller itself, the question of direction of rotation and the relative position of the propeller with respect to the skin of the ship; finally also the question of erosion.

Figure 39 shows one of the four similar, except for direction of rotation, propellers which were delivered with the ship. Their diameter is 5000 millimeters (16 feet 4.85 inches), pitch 5200 millimeters (17 feet 0.73 inches), the developed area 11 square meters (118 square feet); their pitch is constant. These dimensions were determined in accordance with data obtained from systematic propeller experiments in the Berlin Experiment Station (Dr. Schaffran) and the correctness of these dimensions checked by towing a self-propelled model in the Hamburg Model Basin (Dr. Kempf), the satisfactory results achieved in operation also tend to justify the correctness of propeller dimensions.

As far as the direction of rotation of the propellers is concerned, the arrangement which we chose for the *Berengaria* before was given preference, namely—both starboard and both port propellers turn outboard when seen from above. However, even this arrangement was checked again by model experiments in the Hamburg Model Basin and gave very satisfactory results, although not so good as the arrangement when the inner propellers turn outboard and outer propellers turn inboard, when seen from above. It was known, however, that this latter arrangement frequently affected the maneuverability of the ship unfavorably and for this reason the former was given the preference. The arrangement chosen has proven itself eminently satisfactory in this respect and the maneuverability of the ship leaves nothing to be desired.

As far as relative position of propellers to the skin of the ship is concerned, it was held that the shortest distance occurring between blade tip and ship's hull any time throughout the revolution should be not less than 1 to 1¼ meters (39.37 to 49.21 inches) to prevent the generation of vibration in the ship's after body. The final clearance obtained is equal to 1.20 meters (47.24 inches) for the inner propellers and 1 meter (39.37 inches) for the outer. Other designers may consider these clearances as insufficient, but I believe that a further increase in propeller clearance would result in undue lengthening of the stern tube, in which case the support of the propeller would suffer, so that the transverse forces generated by it would transmit ship's vibration to the after body of the ship all the worse.

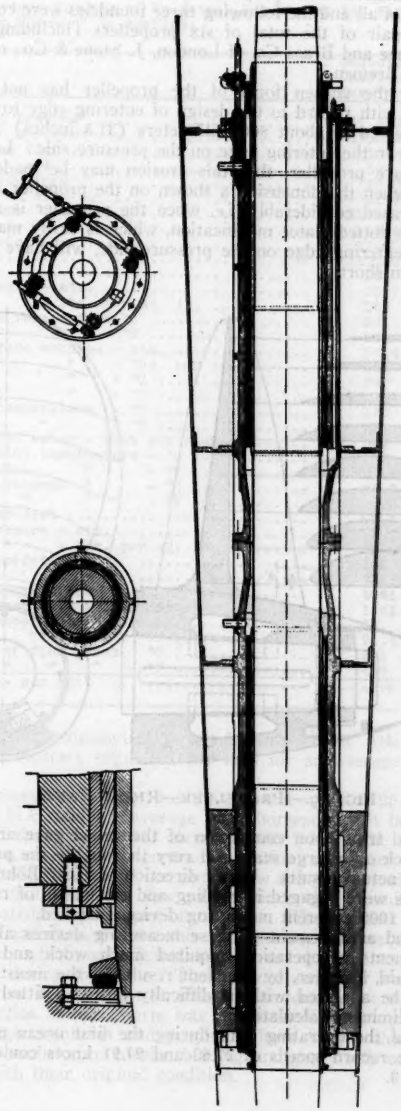


FIG. 38.—STERN TUBE.

To prevent dangers from propeller erosion, the best available material was chosen first of all and the following three foundries were commissioned to furnish each a pair of the total of six propellers (including two spares) Manganese Bronze and Brass Co. of London, J. Stone & Co., of London, and Atlas Werke of Bremen.

Unfortunately the chosen form of the propeller has not proven itself entirely suitable with regard to the design of entering edge to resist erosion, and erosion occurred at about 800 millimeters (31.5 inches) radial distance from the axis near the entering edge on the pressure side. Later on it was proven on a spare propeller, that this erosion may be made to disappear almost wholly, when the dimension a shown on the propeller drawing (Figure 39) is increased considerably, *i.e.* when the propeller is made approximately as shown dotted; later modification, which is easily made by suitably chamfering the entering edge on the pressure side, will have conquered the danger of erosion shortly.

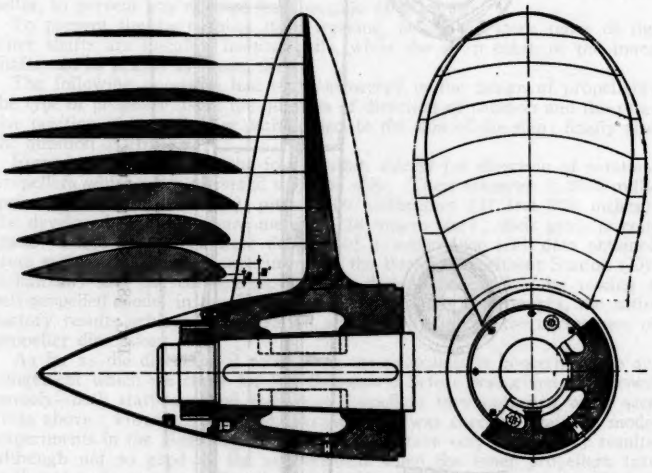


FIG. 39.—PROPELLER—RIGHT HAND.

Extensive trial trips upon completion of the vessel gave an excellent opportunity to check on a large scale and very thoroughly the preliminary calculations by the actual results. Under direction of Herr Böhm 60 engineers and 30 assistants were engaged in reading and evaluation of results obtained from more than 1000 different measuring devices installed.

The choice and arrangement of these measuring devices alone, restricted by the requirements of operation, required much work and consideration, which were repaid, however, by excellent results of the measurements, these not only could be analyzed without difficulty but also fitted well into the scope of the preliminary calculations.

An abstract of the operating data during the first ocean crossing of the vessel, when the record speeds of 27.83 and 27.91 knots could be made are shown on Table 3.

Table 3. Average Figures of Principal Results of the First Trip of the "Bremen" to America.

	Outbound Cherbourg-New York.	Homebound New York-Plymouth.
Displacement leaving	51,830 t	54,000 t
" arriving	47,350 t	47,350 t
Draft leaving fore	32'.	33'6"
" " aft	32'	32'8"
" arriving fore	27'8"	27'10"
" " aft	31'9"	31'7"
Total distance	3164 s m	3064 s m
Hours steamed	113.42	110.30
Speed in knots	27.83	27.91
S.H.P.	112,500	114,000
R.P.M.	194	192.
Boiler pressure - atm.	22.7	22.9
" " - lbs. per sq. in.	322	325
Boiler steam temperature °C	391	388
" " " °F	736	730
Pressure before nozzles - atm.	19.6	19.65
" " " - lbs. per sq. in.	278	279
Temperature " " - °C	385	381
" " " - °F	725	718
Feed water temperature - °C	122	121
" " " - °F	254	250
Weight of feed water - tons per hour	561	558
Sea water inlet temperature - °C	18	19.3
" " " " - °F	64.4	66.7
" " discharge " - °C	26.9	27.7
" " " " - °F	80.4	81.9
Vacuum in per cent	93.3	93.0
Fuel oil pressure - atm.	13.0	14.0
" " " - lbs. per sq. in.	184.6	198.8
Fuel oil temperature - °C	112	113
" " " - °F	234	235
Total fuel consumption	4091 t.	4862 t.
Fire room pressure - inches of water	1.61	1.73
Fire room temperature - °C	33	34
" " " - °F	91.4	93.2
Temperature of flue gases - °C	231	225
" " " " - °F	448	437
CO_2 content - per cent	12.2	11.4

The average fuel consumption for 24 hours over the Atlantic Ocean was 894 tons. The contract stipulated 825 tons for an average speed of 26.25 knots.

Since the horsepower required for the contract speed of 26.25 proved to be about 87,000 S.H.P. and the average shaft horsepower of both trips of the first crossing of the Atlantic was about 113,500 S.H.P., the above figure for fuel consumption corrected for contract conditions and speed will give a fuel consumption of 685 tons, or 17 per cent below the guaranteed.

On July 5, 1930, one year has passed since the commissioning of the *Bremen* after satisfactory completion of trials. The builders of the ship can look back with satisfaction upon this trial period, because no faults of the propelling plant, which necessitated repairs or changes worth mentioning, have shown up during that time. The turbines and their blading as well as the reduction gear required not an iota of maintenance work, so that even a thorough inspection of these parts was not deemed necessary; occasional inspections through manholes and peepholes have shown that no noticeable changes in the condition of turbine blading and gear teeth could be detected as compared with their original condition.

In addition to the above mentioned erosions of the propellers only such difficulties as would normally occur in smaller and normally stressed propelling plants and which can properly be classed as post-trial corrections, have been experienced.

Out of the 23,500 condenser tubes of normal composition nine sprang a leak and had to be replaced, while only 1-2 were replaced in one of the condensers equipped with 7850 tubes of copper-nickel alloy (see above). Out of the 36,635 boiler tubes about 30 had to be plugged due to crack formation and all these tubes were found to be in the first rows of the tube nests nearer the fire. The tube failures with only very few exceptions were found in the boilers designated for port use, and therefore subject to variable and consequently more unfavorable operating conditions. In addition to the above mentioned boiler tube failures 3 of the 606 superheater elements also showed cracks; all of them being in one and the same superheater the whole unit was replaced.

The copper cooler pipes of the small oil coolers for the blowers, main circulating water pumps and Diesel engines had to be replaced by pipes of copper-nickel alloy, due to signs of corrosion showing up in the first two of the above mentioned auxiliaries. Seven cast iron valve housings of auxiliary feed water pumps cracked from water hammer and had to be replaced. The above, in addition to the customary renewal of gland packing material and the like, which by the way had to be done less frequently than usual, comprises all the repairs and renewals made during the first year of operation. Without this exceptional reliability of the propelling plant it would have been impossible to maintain such a strenuous schedule during the main traveling season, which from May to October allowed the vessel an average of only 72 hours between the moment of touching the dock upon arrival and the time of departure at both terminal ports.

CONCLUSIONS.

The turbines and boilers of the steamship *Bremen* were designed in accordance with the general principles, combining economy specified in the contract with weight reduction necessary to obtain the speed. Considerable amount of leeway was thus given the designer to embody the most important requirements of the propelling plant of a transatlatic liner—reliability.

The question remains whether shipowners and designers of the liners now being built will remain on the well-proven ground of the design principles, as embodied in the propelling plants of the *Bremen* and the new turbine-driven ships of the Canadian Pacific Steamship Company, for instance, or whether the responsible creators of these new installations will avail themselves of the newest or at least newer knowledge of marine engineering art.

The development in the realm of propelling plants for high speed liners must proceed along the following three lines: reduction in fuel consumption, reduction in weight and reduction in space requirements, and it is a question what success the application of the new ideas will show in any of these three directions. It is likely that the steam turbines with reduction gears will maintain their lead because Diesel engine drive suffers from the dangers of vibrations, while electric drive is handicapped by dangers from armature troubles, excessive weight and higher cost being also the subject of much concern.

Should we thus use steam again, the question of boilers will require considerable attention. The steam pressure, which is only 24 atmospheres (341 pounds per square inch) in the *Bremen*, has since been raised to 28 atmospheres (398 pounds per square inch) and higher, on the newer transaltantic passenger liners. Within the next few years this pressure will hardly be

raised above say 35 or 40 atmospheres (497-568 pounds per square inch) at the most. The jump to the so-called "highest pressures" of 80-100 atmospheres and more (1136-1420 pounds per square inch) will hardly be ventured so soon, since there is absolutely no experience available on the subject of how ship boilers of such type might be expected to stand up and besides, they offer altogether too many questions of design and operation. I wish to remind only of the question of preparation and deaeration of feed water, the standing-up of boiler tubes under continuous operation, the flange connections and last but not least, the high pressure turbines themselves.

One can on the other hand claim the almost certain arrival of boiler types, which will permit considerably greater heat loads per unit of heating surface, through ingenious utilization of radiating heat, elimination of brickwork and improvements in water circulation, thus improving their efficiency. Such an evolution alone will be sufficient to eclipse the propelling plants of the *Bremen* era.

As far as the improvement of the turbine itself is concerned, this is only possible, after all the well-known factors tending towards highest efficiency have been embodied, by the increase in rotative speed (R.P.M.) and this in turn depends upon finding materials and designs of rotating parts, including blading, which will be able to withstand the increasing centrifugal stresses.

The efficiency of the best land steam turbines with peripheral speeds up to 300 meters per second (984 feet per second) is about 82 per cent, while for marine turbines of the *Bremen* era, it is in the neighborhood of 78 per cent. An improvement of about 5 per cent as compared with the best attainable performance is therefore possible, though we must not be blind to the fact that we thereby come nearer to the limit of reliability.

Thus the problem of the best propelling plant for high speed transatlantic liner will remain, no matter how engineering science will progress, an exceedingly captivating play of compromise to the designer, a delicate balance between operating economy, space economy and weight saving with unimpaired reliability always.—Schiffbau, November 1, 1930.

BOOK REVIEWS.

NON-INTERPOLATING LOGARITHMS COLOGARITHMS AND ANTILOGARITHMS. By Frederick W. Johnson, M. A. Published by The Simplified Series Publishing Company, 1381 Third Avenue, San Francisco, California.

As the title page states this book of tables is "Arranged so as to give Four- and Five-Place Logarithms and Antilogarithms and Four-Place Cologarithms by mere Inspection without any Calculation Whatever; and Provided with a Thumb-Index Enabling the User to Turn Instantly to Any Value Recorded in the Tables."

In an introduction of 23 pages the author gives a clear exposition of the use of logarithms in general calculations and explains in detail the use of the tables as specially arranged in the remaining 93 pages of the 6 × 8½ inch book, a size very convenient for carrying about as well as for desk use.

Besides the tables mentioned above, Tables A, B, C and D are provided for the accurate determination of the logarithmic trignometric functions of small angles (0 degrees to 2 degrees-3 degrees or 87 degrees-88 degrees to 90 degrees) where interpolation cannot properly be used; and table E gives values and corresponding logarithms of (a) International Atomic Weights, (b) Metric Conversion Factors, (c) Chemical and Physical Constants, (d) Frequently used Mathematical Constants, (e) Common and Decimal Fractions.

The aim of the author to reduce fatigue to a minimum and make possible rapid and accurate logarithmic calculations has been well achieved in the excellent arrangement of the tables which therefore should be very useful to engineers and others whose work requires and is satisfied by logarithms correct to four and five places.

H. F. D. Davis.

JAHRBUCH DER HAFENBAUTECHNISCHEN GESELLSCHAFT (YEARBOOK OF PORTBUILDERS SOCIETY). PUBLISHED BY VDI-VERLAG, BERLIN, 367 PAGES, 322 FIGURES—PRICE BOUND 45 R.M.

To keep up with modern rationalization and retrenchment policies the Society has decided to publish in future the proceedings of two years in one "yearbook," hence the current XI volume contains the papers presented at its meetings for the years 1928 and 1929.

The first part (1928) consists of papers on "The world economic importance of Kiel Canal," "Marine Railways and Docks in Ports," "On modern breakwaters and future depth of approaches and ports" as well as the following articles devoted to Baltic ports exclusively—"Shipbuilding berths and piers of the Deutsche Werke A.G. in Kiel," "Port facilities of Rendsburg on the Kiel Canal," "Sea and land Airport Travemünde near Lübeck," "Filsits Commerce and Port facilities," "The building of a warehouse for box goods in Stettin," "Light signals between Stettin and Swinemünde."

The second part (1929) consists of two papers on "The Elbe and Its Relation to the Seaports" and one on "Rationalization in Operation of a Sea-port." Besides these are four articles on inland waterways—"The relation between port development and railroad rates in Saxony," "The Midland Canal," "The Growth of Port Facilities in Magdeburg" and "Leipzig and Midland Canal"; a review of "Harburg-Wilhelmsburg extensions in the port of Hamburg for 1924-29"; a thorough analysis "On the Question of Lowering Ground Waters During Port and River Construction," and ends with an excellent resumé of "Proposals for the extension of free port of Barcelona," giving details of German design which won the prize in the international competition in 1927.

The book has the excellent appearance one expects from this society and the permanency of the technical value of its contents can hardly be doubted.

E. C. MAGDEBURGER.

THE MODERN STEAM TURBINE. By E. A. Kraft, Honorary Professor at the Charlottenburg Technlcal University. Director of the A.E.G.-Turbine Works. Berlin 1930. VDI-Verlag GmbH. Price $5.00.

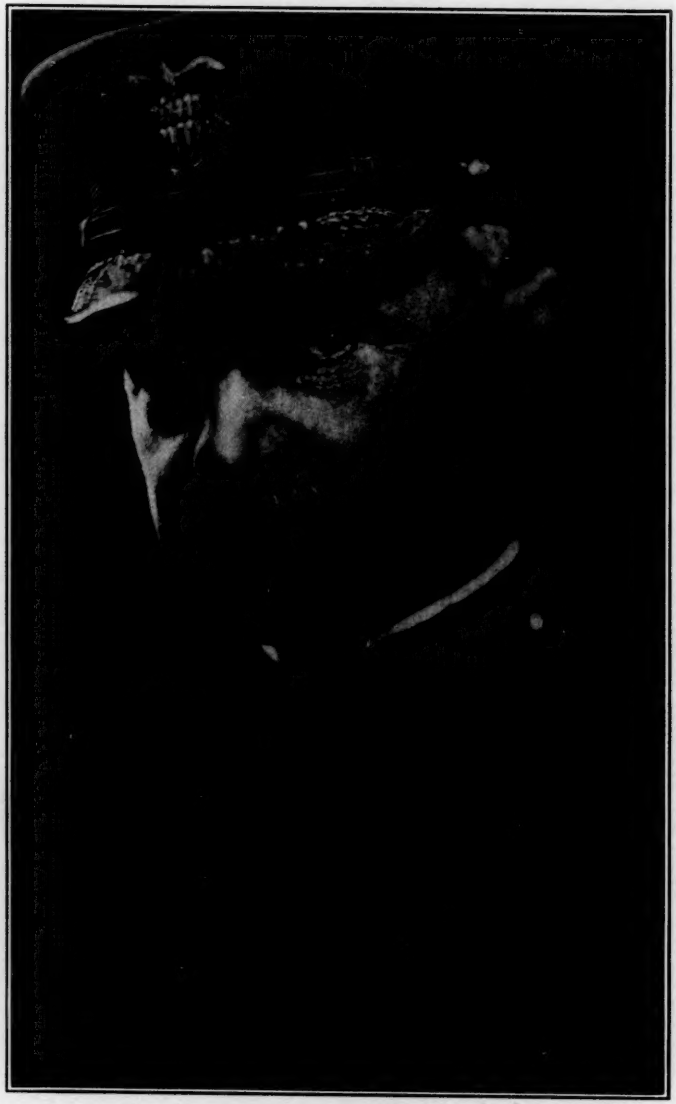
This latest English edition by Dr. Kraft is an excellent summary of the progress made in Steam Turbine design during the past few years. Though primarily covering land installations, a great many of the principles are directly applicable to Marine Turbines. It does not deal with either the theory or general design of the turbine as these subjects are amply covered by many standard publications. The book is divided into five main sections as follows:

I. Methods of attaining higher economy.
II. Technical factors limiting the design.
III. Principles of design.
IV. Practical application of the principles of design.
V. Condensers and their auxiliaries.

The book gives, in a compact form, the effect on economy attained by variation in steam pressure and temperature, back pressure, interstage reheating, regenerative feed-water heating and power generation from process steam together with the latest progress made in the design and materials of all parts of the turbine.

200 pages and 250 illustrations of valuable information.

O. L. Cox.



CHARLES W. DYSON

ASSOCIATION NOTES.

REAR ADMIRAL CHARLES WILSON DYSON, U. S. N.

AN APPRECIATION BY WALTER M. MCFARLAND, FORMERLY CHIEF ENGINEER, U. S. NAVY.

The "Old Engineer Corps" of the Navy and the Marine Engineering Profession suffered the loss of a highly distinguished member, who had long filled a position of great importance and had attained an international reputation, by the death on October 25, 1930, of Rear Admiral Charles Wilson Dyson, in his 69th year. He had retired for age in 1925, but had continued in the active practice of professional work until a few months before his death. It often happens that an eminent engineer has shown as a boy evidence of special aptitude for mechanisms or mechanical processes, but there are no legends about engineering precocity by our lamented friend. His case was the more frequent one of the reaction of a fine mind to its environment and the gradual growth of highly capable initiative and ripened judgment to form the eminent and dependable leader of the profession.

He was born in Cambridge, Maryland, December 2, 1861, the son of Reverend John and Mary Elizabeth (Wilson) Dyson. He was educated in the public schools and graduated from the high school of Norristown, Pennsylvania, in June, 1879. He entered the United States Naval Academy as a Cadet Engineer, after competitive examination, October 1, 1879. Before graduation, and as a result of the Act of Congress passed in 1882, the Cadet Engineers at the Naval Academy were combined with the cadet midshipmen to form a single class of naval cadets. He graduated in June, 1883, as a "Single number" in this combined class which consisted of fifty-four members, among whom were a number who afterwards, like himself, became distinguished in the Service and also others who went into civil life and have attained distinction there.

During the first fifteen years of his naval career after graduation about two-thirds were spent at sea on various ships and stations. During the same period he was on shore duty at the Navy Yard, Boston, for about two and a half years, and as consulting engineer for the U. S. Fish Commission for about the same time. He had chosen service with the Engineer Corps on final graduation in 1885 so that, when the Personnel Bill of 1899 became effective, he was amalgamated a second time from engineering duty into the Line. He was one of those who had the option of qualifying for general duty or following engineering duty only. He chose the latter. He had further sea service on various vessels of about four years, concluding as Fleet Engineer of the Asiatic squadron. From this time till retirement his duty consisted of the design and inspection of the machinery of the new vessels of the Fleet.

His work in the Design Division of the Bureau of Steam Engineering began in 1901, under Chief Engineer (afterwards Admiral) Frank H. Bailey, one of the ablest designers ever in the Bureau, thus giving the young officer the best opportunity for fine professional training and experience. From 1909 to 1913 under Admiral Cone, and again from 1914 to 1921 under Admiral Griffin, he was Chief Designer and responsible for the designs of greatest individual power and finally for the largest aggregate power for vessels of all types in the history of the Navy. In giving due credit to one able man we must not forget that others had a share, such as Emmett for the electric drive, and other manufacturers for the design of their specialties, and finally the Engineer-in-Chief with full official responsibility for the design and performance of the entire machinery installation. If there was any failure, the blame would all be laid on the Chief, so that he is entitled also to full credit. In this connection, it must not be forgotten that the electric drive might never have been used had it not been for the decision of Admiral Cone to install it in the *Jupiter;* and that its use in the Battleships and Battle Cruisers is due to its advocacy and defense, against much acrimonious opposition (and from some prominent engineers) by Admiral Griffin.

Dyson's designs covered machinery for naval vessels of every type from motor launches, submarines and destroyers to battle-

ships and battle cruisers. Probably his greatest pride was in the machinery of the Battle Cruisers *Saratoga* and *Lexington* which have developed the greatest horsepower ever put in a vessel; over 200,000.

The readers of the JOURNAL are so familiar with the routine which obtains in connection with naval vessels built by contract that it is unnecessary to emphasize the fact that the plans as prepared by the Government designers are usually of a general nature, and the details are prepared by the contractor's designers to meet the Government specifications. During the time that Admiral Dyson was Chief Designer of the Bureau of Engineering his relations with outside designers were very pleasant and the writer heard him say that he looked on them as consulting engineers to the Bureau. When it is remembered that these engineers included such talented men as Doctor Charles F. Bailey, Doctor John F. Metten, Mr. Charles P. Wetherbee, Mr. Luther D. Lovekin, Mr. Robert Warriner, Mr. John F. Nicholls and other leaders, it will be realized that their ideas and comments must have had an appreciable effect on the designs of the completed machinery. This in no way detracts from the credit due to Admiral Dyson as Chief Designer and Admirals Cone and Griffin as the officers finally responsible for the whole design. As Melville used to say to those of us who were boys to him and ready to work for him without stint—"There is glory enough for all of us." Those who were close to him know how cheerfully he gave full credit to all his assistants for originating ideas or making suggestions for improvement. The total horsepower of all machinery which was designed under Dyson's supervision amounted to more than 10,000,000.

Such a record would be more than sufficient as a monument to the memory of any engineer, particularly when it is possible to add to the recital of the enormous amount of power the fact that all of these designs were highly successful. There were indeed no failures. In addition to this, however, is the part of Admiral Dyson's work by which he will probably be longest remembered, namely his devotion for almost thirty years to improvement in the design of screw propellers. The writer's own engineering work since leaving the Navy has been along lines other than those comprehending propeller design so that he has believed it desirable in

paying proper tribute to Admiral Dyson's remarkable work, to present a criticism from one familiar with the latest refinements in propeller design. The following comments are from a friend who is one of the most brilliant of the younger engineers of today, and who has already achieved a high reputation for engineering work involving abstruse mathematical problems:

"In the preface to the first edition of his work on Propeller Design, Admiral Dyson states:

"'In 1901, while serving as an assistant in the Bureau of Steam Engineering, U. S. Navy Department, I was requested by the Engineer-in-Chief, the late Rear Admiral George W. Melville, U. S. N., to prepare a paper on the performances of the screw propellers of naval vessels.

"During the preparation of this paper I became so interested in the subject that I have continued the study of it up to the present day'—and it may be added that this interest continued up to the time of his death.

"Dyson's propeller methods are largely empirical. They are based upon a study of the performance of actual propellers associated with particular hulls, as revealed in trial trip data. Dyson assiduously collected all of these trial data which he could obtain, rejected the worthless, sorted the remainder, tabulated and plotted, deduced co-efficients and equations for the curves.

"Starting in 1901 with the trial results of a few naval vessels, the Dyson method grew by an evolutionary process for twenty-five years. The data for additional vessels were added, and those which were found to be unreliable discarded. The form of presentation was changed again and again as he devised methods which he considered superior, until his final charts represent the accumulated experience with hundreds of vessels.

"It is sometimes stated that Dyson's methods are entirely empirical and without theoretical foundation; but he denied this, stating that they originally were based on the Froude theory, as expounded by Barnaby. The distinctive features of Dyson's method were his careful study of the influence of hull form on propeller performance, and his use of the trial data of actual propellers, rather than model tests. Dyson constantly insisted upon the importance of these points—that only the most reliable trial

trip data should be used, 90 per cent being worthless, and that the hull form was of utmost importance in influencing propeller design.

"It must be conceded that Dyson's works are exceedingly difficult reading. He introduced a multitude of terms and symbols peculiar to his method, often without a clear explanation of their meaning. The result is that all but the most patient students soon become discouraged. However, those able and willing to make a thorough study of his methods have found them of enormous value in propeller design. In extenuation of the difficulties of the Dyson method, it must be noted that the study of propellers is an extremely intricate one; it is intricate primarily because of the many variables involved. It is doubtful, therefore, if any system of propeller design, which is not of complex form, can adequately take into account all the factors which influence propeller performance."

Obviously, the familiarity with all phases of propeller design, resulting from the unusual opportunity for the careful study of the trials of each new design, enabled Dyson to obtain results that were more and more nearly perfect as time went on. The two great ships already referred to, the *Saratoga* and *Lexington*, were not given their trials until after he had retired but he was, of course, intensely interested in their performance. The writer well remembers the delight with which he told of the very close agreement of the trial trip performance, as plotted, with the curve of anticipation as laid down when the vessels were designed, and in which the design of the propellers was a very important part.

Reference has been made to the first edition of his work on propeller design. Two other editions were published later, the last one shortly before he retired from active duty. At that time, marine affairs were at a very low ebb, and no firm was willing, at its own risk, to undertake the publication of such a work. Believing that this latest and most valuable information, which would thus be made available to the profession, was worth a serious effort to secure its publication, the Admiral discussed the matter with firms interested in shipping and shipbuilding, many of whom joined in the underwriting of the third and last edition of his work. This is a compliment which only once before has been

paid to the work of any naval engineer. Just after the Civil War, the classic work by Admiral Isherwood, the great Engineer-in-Chief of the Navy during the Civil War, entitled "Experimental Researches in Engineering," was published by subscription raised among the profession. It is very gratifying to know that Admiral Dyson has established a special bank account with the receipts from the sale of this last edition so as to reimburse the underwriters. There is reason to believe, on excellent authority, that before his death he had, in fact, repaid the entire amount advanced by these guarantors, so that, in effect, so far as personal remuneration is concerned, this monumental work is his gift to the profession.

Besides his publications on screw propellers, Dyson brought out, during the World War, a revision of Professor Durand's well-known treatise on "Marine Engineering." This was a book which could be sold at a moderate price, and it appeared when there was a great demand for just such a work, so that it is believed that he received some material compensation for his efforts. He also contributed articles, chiefly on the subject of screw propellers and machinery design, to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS and to the proceedings of other technical societies.

Such an able designer could hardly escape being an inventor, and he took out a number of patents. They were generally in the nature of modifications and improvements of existing methods rather than discoveries of great originality. It is understood that he obtained financial reward from some of them, but as a whole they were beneficial to his professional reputation rather than to his purse.

He was retired in accordance with statutory rule December 2, 1925, on attaining the age of sixty-four years. He was entirely too active to drift into a life of leisure; and he continued work principally in connection with the design of screw propellers for the merchant marine. A number of important vessels were fitted with propellers of his design and always with benefit in the way of improved results. The most notable case, because on such a huge scale, was the new propellers for the S. S. *Leviathan* of the United States Lines. Reliable information is to the effect that

these new propellers secured a saving of nearly 800 tons of oil per round trip. On this basis and figuring on thirteen round trips per annum, the money saving, depending upon the price of oil, would be from Seventy Thousand to One Hundred Thousand Dollars a year.

Admiral Dyson's professional work and reputation were so well known that, at the Commencement of Stevens Institute of Technology on June 7, 1930, the honorary degree of Doctor of Engineering was conferred upon him. In presenting Admiral Dyson for a degree, President Harvey N. Davis read the following citation:

"Mr. Chairman of the Board of Trustees: I present to you for the degree of Doctor of Engineering, honoris causa, CHARLES WILSON DYSON, Rear Admiral in the United States Navy, whose engineering services to the sea forces of this nation through fifty-one years have given men of commerce and men of peace in all nations a new command over the deep and a new freedom from its perils. Under his responsible care, not only was the entire American Fleet of today planned and constructed but the whole mechanism of the application of power to propulsion was reorganized; he developed a method for the design of screw propellers and himself designed ninety per cent of the propellers in use in the navy today, as well as many of those on the larger merchant ships under the American Flag. To the titles and honors conferred upon him by the nation we ask him now to add the honorary degree of Doctor of Engineering."

The Admiral's services during the War were of great value, and the Naval Board of Awards recommended him for the Distinguished Service Cross and the Distinguished Service Medal. The citation for the Distinguished Service Cross is as follows:

"For exceptionaly meritorious service in a duty of great responsibility in charge of the Division of Design of the Bureau of Steam Engineering, and in immediate charge of work on the design of machinery for destroyers, *Eagles*, submarine chasers, and mine sweepers, and of the alterations and additions to merchant vessels, yachts, etc., to make them suitable for service with the Navy."

The citation for the Distinguished Service Medal is as follows:

"For exceptionally meritorious service to the Government in a duty of great responsibility in charge of the Design Division of the Bureau of Engineering and particularly for the design of the propellers of the aircraft carriers *Saratoga* and *Lexington* and of many other naval vessels which have been made by him personally and which have proved very successful on trials. Rear Admiral Dyson, as a result of his ability, study and application, is recognized as one of the foremost authorities in the world in the field of propeller design. During his long years of service in the Navy he has given it, without stint, the benefit of his knowledge and experience and the success of the machinery installations of many of our vessels is due to his thought and effort."

It was only natural, after his long service in the Bureau of Engineering and his recognized eminence as a designer, that Admiral Dyson, upon the retirement of Admiral Griffin, should have aspired to the position of Engineer-in-Chief of the Navy and Chief of the Bureau of Engineering. If the entire duty of the Engineer-in-Chief consisted in the design of machinery, possibly Admiral Dyson would have received the appointment. That, however, is only a part of the duties of the Chief of Bureau who, to be successful, must be a great executive and administrator. Indeed, there are many who think that this phase of the duty is even more important than that of design, inasmuch as an officer who is a competent executive as well as an able engineer would be sure to surround himself with the very best designers in the Service.

The writer's acquaintance and friendship with Admiral Dyson extended over a period of more than forty years and at times was quite intimate. He has had the opportunity of knowing the esteem and even affection in which the Admiral was held by his associates. His superiors have commented most favorably on his loyalty and their satisfaction in being able to rely on him for the best results in his department. Subordinates have spoken of him in terms of highest regard and affection.

He was very fortunate in coming at the right time into a position where his talents had fine opportunity for display. Macaulay in one of his essays says in effect that the reason for Sir Christopher Wren's great reputation was because he had the op-

portunity, never equalled elsewhere in the world history, of rebuilding London after the great fire of 1666. Dyson's case was somewhat similar, in that he was the Head of Machinery Design for the Navy during the very best era of its building, comprehending the decade before the Great War and the period of the War itself, when the increase of the Navy was at a rate which had never before been approached. Fortunate indeed is the man who, when his opportunity for great things arises, measures up to it. This can be truly said of Dyson and it is probably the greatest compliment that he would have asked.

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ELECTION OF OFFICERS.

Ballots cast for officers of the Society for 1931 were counted on December 27, 1930, and the following were declared elected:

President:
Rear Admiral H. E. Yarnell, U. S. N.

Secretary-Treasurer:
Captain O. L. Cox, U. S. N.

Members of Council:
Rear Admiral John Halligan, U. S. N.
Captain Ivan E. Bass, U. S. N.
Captain H. S. Howard (CC), U. S. N.
Captain John Q. Walton, U. S. Coast Guard.
Commander Bryson Bruce, U. S. N.
Mr. W. M. McFarland.
Mr. J. F. Metten.

FINANCIAL STATEMENT.

Following is a financial statement for the calendar year 1930:

RECEIPTS AND EXPENDITURES.

Receipts.

Publication:			
Dues	$5683.75		
Subscriptions	2715.85		
Sales	664.17		
Advertisements	4081.50		
Exchange	1.37		
		$13,146.64	
Interest on investments and bank account		907.27	
			$14,053.91

Expenditures.

Publication:			
Printing	$7334.10		
Engraving	1175.87		
Manuscript	1028.25		
Postage	139.03		
Commission and Discounts	243.05		
		$9,920.30	
Salaries		2,700.00	
General Expense		284.90	
Banquet 1930		103.06	
Current Profit and Loss		215.95	
			13,224.21
Net Gain			$829.70

MEMBERSHIP.

The following members have joined the Society since the publication of the last previous JOURNAL:

NAVAL.

Bednar, A., Naval Academy 1924, care The B. F. Goodrich Rubber Co., Akron, Ohio.

Bellinger, Lorentz D., Ensign, U. S. N. R., Bailey Meter Co., 1050 Ivanhoe Road, Cleveland, Ohio.

Brownell, T. C., Neptune Meter Co., 50 East 42d St., New York, N. Y.

Buckmaster, Elliott, Lieut. Commander, U. S. N.

Curry, H. H., Lieutenant, U. S. Coast Guard.

Fisher, William G., Lieutenant, U. S. N.

Flewelling, M. F., Ensign, U. S. N. R., P. O. Box 349, Quincy, Mass.

Holmes, Wilfred J., Lieutenant, U. S. N.

Maury, Sefrein, 825 Madison Avenue, New York, N. Y.

Meyer, H. A., Ensign, U. S. Coast Guard.

Robinson, Selden H., Lt. Commander, U. S. N. R., 804 Hyde St., San Francisco, Calif.

Rowe, George E., Lieutenant, U. S. N. R., New York American, 1 Hamson Place, Brooklyn, N. Y.

Smith, Lybrand P., Lieut. Commander, U. S. N.

Woyciehowsky, S. J., Lieutenant, U. S. Coast Guard.

Zannaras, C. P., Supt. Engineer, High Seas Transportation Co., 1819 Broadway, New York, N. Y.

CIVIL.

Bennett, L. C., Westinghouse Electric & Mfg. Co., 30th and Walnut Sts., Philadelphia, Pa.

Berrian, H. C., Newport News Shipbuilding and Dry Dock Co., Newport News, Va.

Christainsen, Niels, Newport News Shipbuilding and Dry Dock Co., Newport News, Va.

Corse, W. M., 810 18th St., N. W., Washington, D. C.

Craig, J. Norman, 1014 West 6th St., Wilmington, Del.

Pogue, George D., 25 Prospect Place, New York, N. Y.

Tiefel, John C., Westinghouse Electric & Mfg. Co., 30th and Walnut Sts., Philadelphia, Pa.

ASSOCIATE.

Long, Paul M., Marine Sales Dept., Electro Dynamic Co., Bayonne, N. J.

Lorentzen, Poul, 47 Belair Road, Rosebank, Staten Island, N. Y.